Compendium of Scientific, Medical, and Media Findings Demonstrating Risks and Harms of Fracking and Associated Gas and Oil Infrastructure

Ninth Edition

October 2023

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Gas industry site on BLM land, San Juan Basin, New Mexico

The Compendium of Scientific, Medical, and Media Findings Demonstrating Risks and Harms of Fracking (the Compendium) is a fully referenced compilation of evidence outlining the risks and harms of fracking. It is a public, open-access document that is housed on the websites of Concerned Health Professionals of New York (www.concernedhealthny.org) and Physicians for Social Responsibility (www.psr.org).

The eight earlier editions of the Compendium have been used and referenced all over the world. The Compendium has been twice translated into Spanish: independently in 2014 by a Madrid-based environmental coalition, followed by an official translation of the third edition, funded by the Heinrich Böll Foundation and subsequently updated in December 2019 with new data from the sixth edition. The Compendium has been used in the European Union, South Africa, the United Kingdom, Australia, Mexico, and Argentina.

About Concerned Health Professionals of New York and the Science and Environmental Health Network

Concerned Health Professionals of New York (CHPNY) is an initiative by health professionals, scientists, and medical organizations for raising science-based concerns about the impacts of fracking on public health and safety. CHPNY provides educational resources and works to ensure that careful consideration of science and health impacts are at the forefront of the fracking debate. In June 2021, the Ceres Trust granted funding for CHPNY to become a program of the Science and Environmental Health Network (SEHN). Since 1998, SEHN has been the leading proponent in the United States of the Precautionary Principle as a basis for environmental and public health policy. In service to communities and future generations, the Science and Environmental Health Network is a research institution that forges law, ethics, and science into tools for action.

About Physicians for Social Responsibility

Working for more than 50 years to create a healthy, just, and peaceful world for both present and future generations, Physicians for Social Responsibility (PSR) uses medical and public health expertise to educate and advocate on urgent issues that threaten human health and survival, with the goals of reversing the trajectory towards climate change, protecting the public and the environment from toxic chemicals, and addressing the health consequences of fossil fuels. PSR was founded by physicians concerned about nuclear weapons, and the abolition of nuclear weapons remains central to its mission.

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About this Report

The Compendium exists within a moving stream of data. As we prepared this ninth edition, the authors of the Compendium continued to see evidence of the rapid expansion of our knowledge base, which has grown both quantitatively and qualitatively and enables some fairly solid conclusions that, even a few years ago, were emerging concerns. **The risks and harms of fracking for public health and the climate are real and growing.** Many early warnings in our previous editions have been borne out. Further, despite the continuing challenges of exposure assessments, the results of recent studies confirm and extend the validity of earlier findings. We see a growing consistency of evidence across various themes.

Organizational structure

To organize this now-vast body of research and make it accessible to public officials, researchers, journalists, and the public at large, we have created both topical categories and have identified trends within and across these topic areas. The reader who wants to delve deeper can consult the reviews, studies, and articles referenced herein. In addition, the Compendium is complemented by a fully searchable, near-exhaustive citation database of peer-reviewed journal articles pertaining to shale gas and oil extraction, the Repository for Oil and Gas Energy Research, that was developed by PSE Healthy Energy and is housed on its website (https://www.psehealthyenergy.org/our-work/shale-gas-research-library/). As of October 2023, **2,303 published peer-reviewed studies** that pertain to shale and tight gas development were archived in the ROGER database.

In our cataloguing of the findings, sixteen topical categories emerged, and these serve as the chapter titles of the Compendium. Readers will notice the ongoing upsurge in reported problems, making each section top-heavy with recent data. In accordance, the Compendium is organized in reverse chronological order within sections, with the most recent information first. Introducing this compilation of studies is a section of our report called **Emerging Trends,** which identifies strong patterns within and across these topic areas. **Current Political, Cultural, and Economic Contexts** explores the profound crisis that characterizes the fracking industry in 2023.

The Compendium focuses on topics most closely related to the public health and safety impacts of drilling and fracking. These necessarily include threats to climate stability. By 2018 there was extensive documentation of harm. A categorical review of all original research papers published from 2016-2018 on the health impacts of fracking showed that 90.3 percent of studies had already found a positive association with harm or potential harm.[1]

Additional risks and harms arise from industrial activities associated with drilling and fracking operations. A detailed accounting of all these ancillary impacts is beyond the scope of this

[1] Kyle Ferrar, Erica Jackson, and Samantha Malone, "Categorical Review of Health Reports on Unconventional Oil and Gas Development; Impacts in Pennsylvania," Issue Paper (FracTracker Alliance, 2019), https://www.delawareriverkeeper.org/sites/default/files/FracTrackerAlliance_DRKHealthReview_Final_4.25.19_0.pdf.

document. Nevertheless, in this edition we include discussions of impacts from fracking infrastructure that focus on

- compressor stations and pipelines;
- silica sand mining operations;
- natural gas storage facilities;
- the manufacture and transportation of liquefied natural gas (LNG);
- natural gas power plants;
- fracking waste disposal;
- carbon capture and storage and the creation of "blue hydrogen;"
- gas stoves and other household gas-fired appliances.

(Note that threats from flare stacks are included in the section on air pollution.)

Many other relevant concerns—including the use of fracked gas as a feedstock in petrochemical manufacturing—are not included here.

Similarly, this edition of the Compendium does not examine the harms and risks posed by other forms of unconventional oil and gas extraction, such as cyclic steaming (which uses pressurized, superheated water to release oil), microwave extraction (which points microwave beams into shale formations to liquefy oil), and artificial lift (which uses gases, chemicals, or pumps to extract natural gas).

Methodology

For this ninth edition of the Compendium, as before, we collected and compiled findings from three sources: articles from peer-reviewed medical and scientific journals; investigative reports by journalists; and reports from, or commissioned by, government agencies. Peer-reviewed articles were identified through databases such as PubMed and Web of Science and from within the ROGER database. We included review articles when such reviews revealed new understanding of the evidence. We excluded papers that focused purely on methodologies or instrumentation. News articles appearing as individual entries signify reports that contain original research. In many cases, this reportage is based on data collected by industry or government agencies that were revealed by investigative journalists and not otherwise known to the scientific community. While advocacy organizations continue to compile many useful reports on the impacts of fracking and its ancillary infrastructure, these appear in our Compendium only when they provide otherwise inaccessible data.

For purposes of this Compendium, we use the word "fracking" to refer to a collective suite of unconventional oil and gas production methods that depend on hydraulic fracturing to extract dispersed oil or natural gas trapped inside rock layers that would otherwise not flow to the surface. In other words, "fracking" encompasses a range of activities and ancillary infrastructure both before and after the actual fracturing stage, including drilling, flowback, and well completion.

Our entries briefly describe studies that investigated harm, or risk of harm, associated with

fracking, and summarize the principal findings. Entries do not include detailed results or a critique of the strengths and weaknesses of each study. Because much of medicine's early understanding of new diseases and previously unsuspected epidemiological correlations comes through assessment of case reports, we have included published case reports and anecdotal reports when they are data-based and verifiable.

The scientific papers referenced in the dated entries and catalogued within the Compilation of Studies & Findings are current through June 1, 2023. The footnoted citations here in the front matter represent studies and articles that are not referenced in the Compendium itself or which appeared after June 1, 2023 but before we went to press in October 2023.

Within the compiled entries, we have also provided references to articles appearing in the popular press, when available, that describe the results of the corresponding peer-reviewed study and place them in context with the results of other studies. For this purpose, we sought out articles that included comments by principal investigators on the significance of their findings. In such cases, footnotes for the peer-reviewed study and the matching popular article appear together in one entry. We hope these tandem references will make the findings more accessible and meaningful to readers.

Acronyms are spelled out the first time they appear in each section.

For some sources, cross-referenced footnotes are provided, as when wide-ranging government reports or peer-reviewed papers straddled two or more topics.

Citation style

For this ninth edition, footnotes appear in Chicago Manual of Style 17th edition (full note) format. In 2021, a change of ownership at the news organization *E&E News*, from which we have drawn many important reports, placed some previously open-access stories behind a pay wall. In such cases, and when available, we have provided footnotes that direct readers to URLs drawn from the Internet Archive, a 501(c)(3) non-profit organization that maintains open access to many documents by "building a digital library of Internet sites and other cultural artifacts in digital form."

Please note that the date of a Compendium entry sometimes represents the first online appearance of an advance copy or a pre-publication version of the paper, whereas the date in the footnote citation always refers to the formal publication date. Thus, entry dates are not always identical to dates in corresponding footnotes.

The Compendium as a living document

Given the rapidly expanding body of evidence related to the harms and risks of unconventional oil and gas extraction, we plan to continue revising and updating the Compendium approximately every year. It is a living document, housed on the websites of Concerned Health Professionals of New York and Physicians for Social Responsibility, which serves as an educational tool in important ongoing public and policy dialogues.

We welcome your feedback and comments.

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Summary of Findings

As of 2022, hydraulic fracturing techniques had been used on an estimated one million wells across the United States to shatter rock layers and extract the oil or gas trapped inside. With hydraulically fractured shale wells now producing at least 79 percent of U.S. natural gas and 65 percent of U.S. crude oil, fracking, no longer "unconventional," has become the standard method for oil and gas extraction. As fracking operations in the United States and abroad have increased in frequency, size, and intensity, a significant body of evidence has emerged to demonstrate that these activities are harmful in ways that cannot be mitigated through regulation. Threats include detrimental impacts on public health, climate stability, water and air quality, farming and livestock, property values, economic vitality, and quality of life.

Emerging science also shows that fracking is an environmental injustice, with injuries not borne equally by all. Throughout the United States, pregnant women, children, Indigenous people, communities of color, and low-income communities are disproportionately harmed by fracking.

A growing and substantial body of research reveals fundamental problems with the entire life cycle of operations associated with fracking and its infrastructure. Independent, peer-reviewed analyses indicate that fracking is an unpredictable process with innate engineering problems that include uncontrolled fracturing, induced earthquakes, and well casing failures that worsen with age. Intractable problems also include radiation releases; abandoned wells that serve as pathways for contamination; and venting, flaring, and blowdowns that result in methane releases.

As documented in more than 110 studies, toxic air pollution accompanies fracking. More than 200 airborne chemical contaminants have been detected near drilling and fracking operations, and air monitoring has confirmed strikingly high levels of toxic air pollutants in communities near these sites. Of these chemicals, 61 are classified as hazardous air pollutants with known health risks, including the potent carcinogens benzene and formaldehyde. Additional fracking-related air pollutants include diesel exhaust, fine particles, hydrogen sulfide gas, nitrogen oxides, chlorine, and other chemical precursors of ground-level ozone (smog), which can damage respiratory, cardiovascular, and nervous systems. In many cases, concentrations of fracking-related air pollutants in communities where people live and work exceed federal safety standards, even in some rural communities. Research shows that air emissions from fracking and flaring can drift and pollute the air hundreds of miles downwind. Indoor air pollution from gas stoves, which represent the terminus of the fracking pipeline, includes nitrogen oxides, carbon monoxide, fine particulate matter, and benzene. About one in every eight cases of asthma in U.S. children is attributable to exposure to emissions from gas stoves.

Each day in the United States, more than two billion gallons of pressurized fracking fluids are pumped underground for the purpose of extracting oil and gas or, after the fracking is finished, to inject the extracted wastewater into any of more than 187,000 disposal wells across the country. As documented by more than 200 studies, these fracking-related activities have depleted or contaminated water resources, including drinking water sources. Studies from across the United States provide irrefutable evidence that groundwater contamination has occurred as a result of fracking activities and is more likely to occur close to well pads. Spills and intentional discharges of fracking fluids and fracking waste into surface water have profoundly altered the chemistry and ecology of streams throughout entire watersheds, increasing downstream levels of

radioactive elements, heavy metals, endocrine disruptors, toxic disinfection byproducts, and acidity, and decreasing aquatic biodiversity. Demand for water to use in U.S. fracking operations has more than doubled since 2016. The water used for fracking that remains in the shale formation is permanently lost to the hydrological cycle. Studies also show that fracking can deplete streams and aquifers in ways that create water scarcity in drought-prone regions. Along with fracking itself, the injection of fracking waste is a proven cause of earthquakes. The disposal of fracking wastewater remains a problem with no solution.

With more than 17.6 million U.S. residents living within one mile of at least one active oil and gas well, the result is a public health crisis. As documented in more than 120 studies, public health harms now linked with drilling, fracking, and associated infrastructure are well-established. They include cancers, asthma, respiratory diseases, skin rashes, heart problems, and mental health problems. Multiple corroborating studies of pregnant women residing near fracking operations across the nation show impairments to infant health, including birth defects, preterm birth, and low birth weight. Emerging evidence shows harm to maternal health—including elevated risks for eclampsia during pregnancy—and shortened lifespans among older residents living in proximity to oil and gas wells.

Fracking is accelerating the climate crisis. North American fracking operations for both oil and gas are driving the current surge in global levels of methane, a greenhouse gas 86 times more potent at trapping heat than carbon dioxide over a twenty-year period and which has contributed approximately 40 percent of all global warming to date. Methane escapes into the atmosphere from all parts of the extraction, processing, and distribution system, at rates that, as demonstrated through multiple methodologies, sometimes exceed earlier estimates by a factor of two to six. Recent scientific findings indicate that slashing methane emissions is far more critical in halting global warming than previously understood. Liquefying natural gas via super-chilling to allow its overseas transport as LNG adds further to the prodigious greenhouse gas emissions of natural gas obtained via fracking, due in part to the immense energy and evaporative cooling required by the liquefication process.

Carbon capture and storage, now being promoted as a tool to address climate change, is an unproven set of technologies that does not account for methane emissions, cannot obviate the climate damage created by fracking, worsens local air pollution, and, as currently practiced, mostly serves as a tool of enhanced oil recovery that allows depleted wells to produce more oil.

In sum, the vast body of scientific studies now published on hydraulic fracturing in the peer-reviewed scientific literature confirms that the public health and climate risks from fracking are real and the range of environmental harms wide. **Our examination uncovered no evidence that fracking can be practiced in a manner that does not threaten human health directly or without imperiling climate stability upon which human health depends.**

The rapidly expanding body of evidence compiled here is massive, troubling, and cries out for decisive action. Across a wide range of parameters, the data continue to reveal a plethora of recurring problems that cannot be sufficiently averted through regulatory frameworks. The risks and harms of fracking are inherent in its operation. The only method of mitigating its grave threats to public health and the climate is a complete and comprehensive ban on fracking. Indeed, a fracking phase-out is a requirement of any meaningful plan to prevent catastrophic climate change.

The Compendium in Historical Context

2014: New York State fracking ban

The release of the first edition of the Compendium by Concerned Health Professionals of New York in July 2014 coincided with a meteoric rise in the publication of new scientific studies about the risks and harms of fracking. A second edition was released five months later, in December 2014, and included new studies that further explicated recurrent problems.

Almost concurrently, on December 17, 2014, the New York State Department of Health (NYS DOH) released its own review of the public health impacts of fracking. (See footnote 1232.) That document served as the foundation for a statewide ban on high-volume hydraulic fracturing (HVHF), announced by New York Governor Andrew Cuomo on the same day. Its conclusions—

> [I]t is clear from the existing literature and experience that HVHF activity has resulted in environmental impacts that are potentially adverse to public health. Until the science provides sufficient information to determine the level of risk to public health from HVHF and whether the risks can be adequately managed, HVHF should not proceed in New York State.

The New York State Department of Environmental Conservation's final environmental impact statement and attendant Findings Statement incorporated the earlier health review into a larger analysis of the impacts of fracking. (See footnote 936.) The Findings Statement made clear that no known regulatory framework can adequately mitigate the multiple risks of fracking:

> Even with the implementation of an extensive suite of mitigation measures…the significant adverse public health and environmental impacts from allowing high-volume hydraulic fracturing to proceed under any scenario cannot be adequately avoided or minimized to the maximum extent practicable….

2015-2016: Paris Climate Agreement

The third edition of the Compendium, released in October 2015, included the results of the first substantive government reports on the impacts of fracking.

In December 2015, the third edition became the basis of invited testimony at conferences taking place concurrently with the United Nations' climate talks in Paris. Those international negotiations resulted in an historical international accord, the Paris Agreement, which recognizes climate change as a grave threat to public health and establishes as a key goal the need to limit global temperature increases to $< 2^{o}$ Celsius, or, ideally, 1.5^{o} C, above pre-industrial times. As such, the treaty articulates a vision for energy by compelling nations to monitor their greenhouse gas emissions and set increasingly ambitious targets and timetables to reduce them.

The Compendium's fourth edition was released in November 2016, just as the Paris Agreement went into force and as several new studies conclusively demonstrated that expansion of shale gas

and oil extraction was incompatible with climate stability and the goal of rapid decarbonization that it requires. All together, these data show that because of increasing emissions of methane—a powerful heat-trapping gas—the United States was on track to miss its pledge under the Paris Agreement to reduce greenhouse gas emissions 26-28 percent by 2025. (See footnotes 1791, 1792.) The evidence showed that methane leaks from U.S. oil and gas operations were significantly higher than previously estimated, as were U.S. methane emissions overall. (See footnotes 1793-1795, 1801, 1812, 1813.)

2017-2020: Environmental retrenchment and COVID-19 pandemic

The fifth, sixth, and seventh editions (released in March 2018, June 2019, and December 2020 respectively) were all launched in a time of deep environmental retrenchment by the federal government. The Trump administration had announced an era of "energy dominance" based on surging domestic production of oil and natural gas, most of it extracted via fracking. The White House withdrew from the Paris Agreement even as the American Meteorological Society released a major report that identified climate change as a contributor to several recent extreme weather events and even as the Fourth National Climate Assessment confirmed human activities as the dominant cause for ongoing global warming.[2, 3]

Among the more than 100 federal environmental regulations rescinded during this period were many that governed drilling and fracking operations. These included rules requiring companies drilling on public and tribal lands to reduce methane leaks and cut back on flaring and venting, a system for oil and gas facilities to report methane leaks, a rule mandating disclosure of chemicals in fracking fluid on public lands, and tighter standards for wastewater disposal.[4, 5]

By September 2018, the United States had become the world's leading oil and gas producer, surpassing both Russia and Saudi Arabia.[6] Much of that growth was driven by fracking operations in the Permian Basin of West Texas and eastern New Mexico, where 40 percent of U.S. oil is extracted, as the Permian became the leading source of U.S. crude oil exports.[7] By 2019, aggressive attacks on regulatory oversight of U.S. oil and gas extraction had extended to

[2] Stephanie C. Herring et al., eds., "Explaining Extreme Events of 2016 from a Climate Perspective," *Bulletin of the American Meteorological Society* 99, no. 1 (2018): S1–57, https://doi.org/10.1175/BAMS-ExplainingExtremeEvents2016.1.
[3] "Climate Science Special Report: Fourth National Climate Assessment, Volume 1" (U.S. Global Change Research Program, 2017), https://www.globalchange.gov/browse/reports/climate-science-special-report-fourth-national-climate-assessment-nca4-volume-i.
[4] Harvard University Environmental Law Program, "Environmental Regulation Rollback Tracker," 2019, http://environment.law.harvard.edu/policy-initiative/regulatory-rollback-tracker/.
[5] Chris Mooney, "To Round out a Year of Rollbacks, the Trump Administration Just Repealed Key Regulations on Fracking," *The Washington Post*, December 29, 2017, sec. Climate and environment, https://www.washingtonpost.com/news/energy-environment/wp/2017/12/29/to-round-out-a-year-of-rollbacks-the-trump-administration-just-repealed-key-regulations-on-fracking/?utm_term=.f16b4db99128.
[6] U.S. Energy Information Administration, "The United States Is Now the Largest Global Crude Oil Producer," Today in Energy, September 12, 2018, https://www.eia.gov/todayinenergy/detail.php?id=37053.
[7] Kiah Collier, Jamie Smith Hopkins, and Rachel Leven, "As Oil and Gas Exports Surge, West Texas Becomes the World's 'Extraction Colony,'" *The Texas Tribune*, October 11, 2018, https://www.texastribune.org/2018/10/11/west-texas-becomes-worlds-extraction-colony-oil-gas-exports-surge/.

the science underlying the targeted regulations.[8, 9] Unimpeded by federal regulations and driven by fracking, U.S. oil and gas production reached record levels and spurred a massive build-out of fracking infrastructure, leading to large-scale industrialization in formerly rural areas and densely populated communities alike. The Federal Energy Regulatory Commission (FERC) eased the process to build new pipelines while executive orders impeded the ability of states to block pipeline construction.[10, 11] Throughout 2018 and 2019, in the face of flattening domestic demand for gas and falling prices in a closed market, the ongoing fracking boom was increasingly directed at export markets, which prompted the planning of 15 new LNG terminals, beyond the six then in operation.[12, 13, 14]

In 2020, the COVID-19 pandemic slashed global oil demand and sent oil prices to historical lows. In both the gas and oil sectors, the pandemic accelerated job lay-offs that automation had begun. By October 2020, Deloitte had announced that the return on invested capital of oil and gas companies was largely on par with top renewable energy companies, and the International Energy Agency (IEA) reported that the worth of major oil and gas companies had fallen by more than $50 billion, with investment in oil and gas falling by one-third.[15, 16]

2021-2022: Russian invasion of Ukraine

The eighth edition of the Compendium (April 2022) was released during a time of accelerating fracking activity. Much of this activity was being driven by a booming export market as Europe faced a full-on energy crisis following Russia's invasion of Ukraine, which began in February 2022 and is ongoing. With the European Union relying on Russia for about 45 percent of its natural gas imports, the war prompted an urgent and overdue assessment of this relationship. In the short term, this meant relying more heavily on gas from the United States, to arrive as LNG via ship to existing but also new and proposed terminals. In 2022, President Biden pledged to

[8] Jonathan Stempel, "U.S. EPA Is Sued for Ousting Scientists from Advisory Committees," Reuters, June 3, 2019, https://www.reuters.com/article/us-epa-lawsuit/us-epa-is-sued-for-ousting-scientists-from-advisory-committees-idUSKCN1T42H8.
[9] Coral Davenport, "Trump Administration Hardens Its Attack on Climate Science," *The New York Times*, May 27, 2019, sec. Climate and environment, https://www.nytimes.com/2019/05/27/us/politics/trump-climate-science.html.
[10] Rachel Leven, "Drilling Overwhelms Agency Protecting America's Lands," Associated Press, November 13, 2018, https://www.apnews.com/dac08562077c41a8a08845a291cbfb6c.
[11] Nicholas Kusnetz, "Trump Aims to Speed Pipeline Projects by Limiting State Environmental Reviews," Inside Climate News, April 11, 2019, https://insideclimatenews.org/news/11042019/trump-pipeline-executive-order-environmental-review-keystone-xl-clean-water-act-states-rights.
[12] Darrell Proctor, "Plenty of Natural Gas Around-It Just Needs a Market," *Power Magazine*, April 1, 2019, https://powermag.com/plenty-of-natural-gas-to-go-around-it-just-needs-a-market/.
[13] European Commission, "EU-U.S. Joint Statement: Liquefied Natural Gas (LNG) Imports from the U.S. Continue to Rise, up by 181%," press release, March 8, 2018, http://europa.eu/rapid/press-release_IP-19-1531_en.htm.
[14] U.S. Department of Energy, "Department of Energy Authorizes Additional LNG Exports from Freeport LNG," Press Release, May 29, 2019, https://www.energy.gov/articles/department-energy-authorizes-additional-lng-exports-freeport-lng.
[15] Duane Dickson, Tom Bonny, and Noemie Tilghman, "The Future of Work in Oil, Gas and Chemicals," Deloitte Insights, October 5, 2020, https://www2.deloitte.com/global/en/insights/industry/oil-and-gas/future-of-work-oil-and-gas-chemicals.html.
[16] International Energy Agency, "World Energy Outlook 2020," October 2020, https://www.iea.org/reports/world-energy-outlook-2020#.

supply Europe with 15 billion cubic meters (bcm) of LNG, ramping up to 50 bcms annually until 2030.[17]

Even before the EU's war-prompted pivot toward increased reliance on U.S. gas, the swelling global demand had allowed the United States to surpass Australia and Qatar as the world's biggest exporter of LNG. Indeed, by 2022, U.S. LNG exports into the European Union had grown 22 times larger since the July 2018 meeting of U.S. and EU Commission Presidents to diffuse a trade war.[18] The supply for these exports was largely met by U.S. fracking operations, especially in the Permian Basin.[19]

[17] The White House, "FACT SHEET: United States and European Commission Announce Task Force to Reduce Europe's Dependence on Russian Fossil Fuels," March 25, 2022, https://www.whitehouse.gov/briefing-room/statements-releases/2022/03/25/fact-sheet-united-states-and-european-commission-announce-task-force-to-reduce-europes-dependence-on-russian-fossil-fuels/.
[18] European Commission, "EU-U.S. LNG Trade: U.S. Liquefied Natural Gas Has the Potential to Help Meet EU Gas Needs," January 8, 2020, https://ec.europa.eu/energy/sites/ener/files/eu-us_lng_trade_folder.pdf.
[19] Stanley Reed, "Natural Gas Shipments, Mostly from U.S., Ease Europe's Energy Crunch," *New York Times*, February 3, 2022, https://www.nytimes.com/2022/02/03/business/natural-gas-europe-us.html.

Current Political, Cultural, and Economic Contexts

The fracking industry appears once again ascendent in 2023. In the United States, at least five factors appear to be driving this forward motion.

First, no national legislation or policy directive has been introduced to compel a winding down of fossil fuel projects, including fracking operations, or impede the approval of new ones. Both are needed to align the United States with the global goal of net zero carbon emissions by 2050. In the **absence of legally binding mandates**, future U.S. oil extraction plans are now set to release five times more CO2 than remains in the nation's carbon budget.[20]

Second, the Inflation Reduction Act of 2022 provides tax credits that incentivize the use of **carbon capture and storage technologies**, offering financial rewards to oil and gas companies that inject carbon dioxide underground, including for use in extracting more oil and gas out of depleted wells (so-called enhanced oil recovery. See Major Trend 16.) The structure of this tax credit is widely understood as serving as a long-term subsidy to oil and gas extraction operations.

Third, the **ongoing expansion of the petrochemical industry** is creating demand for hydrocarbon feedstocks above and beyond their use in the energy sector. Construction and expansion of steam cracker facilities are proliferating, especially in the Gulf Coast and in Appalachia regions. These facilities turn the oil and gas extracted via fracking operations into ethylene and propylene for use in chemical manufacturing, including plastics manufacturing. The ongoing build-out of steam crackers extends the lifetime of oil and gas extraction efforts even in the face of an ongoing transition to clean, renewable energy sources.[21]

Fourth, **utilities and their regulators** are operating in ways that lock in fossil fuel expansion and prolong natural gas-powered assets that would, in the absence of subsidies by ratepayers, likely be retired. Regulated utilities, which have a monopoly on the sale of electricity and gas to the public, are often allowed to enter into contracts with non-regulated affiliates for gas supply and can also guarantee their debt, both of which enable regulatory approval for fracked gas infrastructural build-out. By guaranteeing the debt of the Atlantic Coast pipeline, for example, Dominion Energy and Duke Energy contributed to regulatory findings that natural gas pipelines offer an affordable solution to energy demands. Furthermore, transmission operators that own fossil fuel-powered utilities are disincentivized to develop transmission capacity from solar and wind-powered resources, with some actively opposing policies to accelerate the development of transmission lines for clean energy. These efforts extend to vigorously obstructing the development of small-scale renewable energy, net metering, and rooftop solar that allow homeowners to generate their own power (distributed energy). Vertically integrated electric

[20] Nick Ferris, "Exclusive: How US Oil Extraction Plans Will Scupper Global Climate Goals," *Energy Monitor*, July 6, 2023, https://www.energymonitor.ai/policy/exclusive-how-us-oil-extraction-plans-will-scupper-global-climate-goals/.
[21] Nicholaus P Johnson et al., "Steam Cracker Facilities in the United States: Operations, Emissions, and Sociodemographic Patterns of Surrounding Populations," *Environmental Research: Health*, June 8, 2023, https://doi.org/10.1088/2752-5309/acdcb2.

utilities thus may invest in transmission capacity that protects the market power of their generation assets and creates a domestic market for fracked gas.[22, 23, 24]

And fifth, **LNG exports** from the United States to Europe remain at record highs as part of a continued policy of both the Biden administration and the EU to replace Russian pipeline gas throughout the European Union with U.S.-sourced gas. LNG imports to Europe soared by 65 percent during the first nine months of 2022 as compared to the same period in 2021.[25] As of January 2023, European companies had signed 15 sale and purchase agreements for U.S. LNG, with most contracts extending for 20 years.[26] This trend has prompted a rush to construct new LNG export and import facilities on both sides of the Atlantic, attract customers, and secure financial approvals in ways that could lock in U.S. fracking operations for decades to come.[27] The United States has, as of this writing, eight operational LNG export terminals. Five others are under construction; plans for 11 others have received federal approval (but not all are financed). Proposals for six more have been submitted for approval.[28] If every proposed LNG terminal were built, the number of LNG export facilities in the United States would quadruple.

In Europe, this build-out is currently being aided by Germany's LNG Acceleration Act, which offers pre-approval for gas import terminals until 2043, provides direct financing, and suspends the need for environmental impact assessments for floating terminals.[29, 30] In January 2023, Germany received its first regular shipment of LNG from the United States into its new

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[22] Aneil Kovvali and Joshua Macey, "Hidden Value Transfers in Public Utilities," *University of Pennsylvania Law Review*, June 28, 2023, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4493284.
[23] David Pomerantz, "Guess Who's Been Paying to Block Green Energy. You Have.," *The New York Times*, July 5, 2023, https://www.nytimes.com/2023/07/05/opinion/utility-bills-clean-energy.html?smid=nytcore-ios-share&referringSource=articleShare.
[24] Elijah de Castro, "Renewable Energy Threatens Utility Profiteers," *The Progressive*, June 15, 2023, https://progressive.org/latest/renewable-energy-threatens-utility-profiteers-decastro-20230615/.
[25] Ciaran Roe, "Europe to the Fore, Elsewhere through the Floor: How LNG Flows Were Turned on Their Head in 2022," *S&P Global Commodity Insights*, October 26, 2022, https://www.spglobal.com/commodityinsights/en/market-insights/blogs/lng/102622-europe-lng-russian-gas-ukraine-war#:~:text=Europe's%20policy%20shift%20to%20LNG,the%20same%20period%20in%202021.
[26] Edward Donnelly, "LNG Fever: European Firms Sign Mega-Contracts as US Shale Gas Imports Boom," *Investigate Europe*, January 9, 2023, https://www.investigate-europe.eu/en/2023/lng-fever-mega-contracts-shale-gas-imports-us/.
[27] Scott Disavino, "U.S. LNG Producers Poised to Leapfrog Rivals with Three New Projects," *Reuters*, February 16, 2023, https://www.reuters.com/business/energy/us-lng-producers-poised-leapfrog-rivals-with-three-new-projects-2023-02-16/.
[28] Federal Energy Regulatory Commission, "North American LNG Export Terminals – Existing, Approved Not Yet Built, and Proposed," July 12, 2023, https://cms.ferc.gov/media/north-american-lng-export-terminals-existing-approved-not-yet-built-and-proposed-8.
[29] Andy Gheorghiu and Regine Richter, "Investing in Climate Chaos: How German Banks and Companies Enable Fracking LNG Projects," April 19, 2023, https://www.duh.de/fileadmin/user_upload/download/Pressemitteilungen/Energie/LNG/US_LNG_terminals_EN.pdf.
[30] German Federal Ministry for Economic Affairs and Climate Protection, "Kreditanstalt Für Wiederaufbau (KfW), Gasunie Und RWE Unterzeichnen MoU Zur Errichtung Eines LNG-Terminals in Brunsbüttel," May 3, 2022, https://www.bmwk.de/Redaktion/DE/Pressemitteilungen/2022/03/20220305-kreditanstalt-fuer-wiederaufbau-gasunie-und-rwe-unterzeichnen-mou-zur-errichtung-eines-lng-terminals-in-brunsbuettel.html.

Wilhelmshaven floating terminal in the North Sea.[31] Also January 2023, Sempra Energy announced it would, beginning in 2027, send one million tons of LNG per year to Poland from the Port Arthur LNG terminal in Texas, which is currently under construction.[32]

However, behind this momentum, a multiplicity of contradictory forces is roiling the oil and gas industry. These make fracking's long-term prospects more uncertain than its ongoing rebound seems to presage. **At least six interlocking factors now impede or are poised to disrupt the North American fracking boom:**

The surging export market has made renewable energy more attractive

The first factor working against long-term viability of the fracking industry is the surging export market itself**.** With more than ten percent of the nation's natural gas production already headed overseas where prices are higher, domestic gas prices within the United States have spiked in turn, making renewable energy resources more attractive.[33, 34] Further growth in the export market will only exacerbate this trend. If all the LNG terminals currently operational plus all those in the permitting process are brought online, half of all U.S. gas production will be headed overseas.[35] Notably, gas consumption for electric power generation in the United States peaked in the summer of 2020 and is likely now in an irreversible decline.[36]

At the same time, further investments in fracking and LNG operations are at odds with trends in the economics of renewable energy. Continuing innovation, increasing economies of scale, and rapid declines in the cost of wind, solar, and battery storage prices have made renewable energy a cheaper alternative than coal and gas for most major economies. A 2022 modeling analysis shows that a 100-percent renewable energy system in the United States would reduce electricity costs, serve as a hedge on inflation, and eliminate an estimated 53,200 deaths each year—along with $700 billion in health costs—from fossil-fuel associated air pollution.[37] Meanwhile, as pointed out by the Institute for Energy Economics and Financial Analysis, oil remains an

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[31] Associated Press, "First Tanker Carrying Liquefied Natural Gas from the U.S. Arrives in Germany," *Los Angeles Times*, January 3, 2023, https://www.latimes.com/world-nation/story/2023-01-03/tanker-liquefied-natural-gas-from-us-arrives-germany.

[32] Reuters, "Sempra Energy Strikes 20-Year LNG Supply Deal with Poland's PKN ORLEN," Reuters, January 25, 2023, https://www.reuters.com/business/energy/sempra-energy-strikes-20-year-lng-supply-deal-with-polands-pkn-orlen-2023-01-25/.

[33] U.S. Energy Information Administration, "U.S. Liquefied Natural Gas Exports Grew to Record Highs in the First Half of 2021," Today in Energy (U.S. Energy Information Administration, July 27, 2021), https://www.eia.gov/todayinenergy/detail.php?id=48876.

[34] Justin Gerdes, "Opinion: LNG Exports Are Backfiring on the US Oil and Gas Industry," Energy Monitor, October 12, 2021, https://www.energymonitor.ai/analysis/opinion-lng-exports-are-backfiring-on-the-us-oil-and-gas-industry.

[35] Ethan Howland, "FERC Clears NextDecade, Glenfarne LNG Export Projects after Revising Carbon, Environmental Justice Reviews," *Utility Dive*, April 25, 2023, https://www.utilitydive.com/news/ferc-nextdecade-glenfarne-lng-export-projects-environmental-justice-carbon/648508/.

[36] Seth Feaster and Dennis Wamstead, "IEEFA U.S.: Power Sector Gas Consumption Has Likely Hit Its Peak" (Institute for Energy Economics and Financial Analysis, February 16, 2022), https://ieefa.org/power-sector-gas-consumption-has-likely-hit-its-peak/.

[37] Mark Z. Jacobson et al., "Zero Air Pollution and Zero Carbon from All Energy at Low Cost and without Blackouts in Variable Weather throughout the U.S. with 100% Wind-Water-Solar and Storage," *Renewable Energy* 184 (2022): 430–42, https://doi.org/10.1016/j.renene.2021.11.067.

inherently inflationary commodity. As oil and gas companies chase reserves that are increasingly difficult to extract, the costs of producing oil and gas are rising even as high prices triggered by Russian's invasion of Ukraine have fallen back in the wake of waning global demand growth.[38] The global demand for natural gas, in particular, is widely expected to begin falling in the years ahead, peaking far sooner than expected and raising the risks that LNG terminals will face financial risk and become stranded assets.[39] The International Energy Agency has sharply reduced its global natural gas demand projections, noting that European gas demand dropped by more than 10 percent in the first half of 2023 and more modestly in the United States.[40]

Fracking contradicts climate change commitments

Secondly, U.S. fracking and its protracted deregulation are at odds with the scientific consensus on the scale and tempo of necessary climate change mitigation and with rising alarm about the climate crisis that this consensus has amplified.[41, 42, 43, 44] In a trilogy of major reports affirmed by other international teams of scientists, the United Nations Intergovernmental Panel on Climate Change (IPCC) emphasized that the world needs to reduce emissions by 45 percent by 2030 and reach net zero by 2050 to avoid the worst outcomes of the climate crisis and avoid wholesale collapse of ecosystems.

In a major review of the findings of climate science released in 2021, the IPCC's first report issued a "code red for humanity," starkly warning of irreversible changes to planetary support systems that have, in some cases, already begun.[45, 46] In 2022, the IPCC released a second report that reviewed the ecological limits of the natural world together with the vulnerabilities and capacities of human societies to adapt to climate change. Noting that some irreversible ecological impacts are already underway, the report concluded that climate change has already pushed some natural and human systems beyond their ability to adapt, thereby harming public health, undermining global food security, and leaving 3.3 to 3.6 billion people living in contexts that are

[38] Clark Williams-Derry, "Declining Supermajors Profits Reveal Flaws in the Oil and Gas Business Model" (Institute for Energy Economics and Financial Analysis, August 9, 2023), https://ieefa.org/resources/declining-supermajors-profits-reveal-flaws-oil-and-gas-business-model.
[39] Mike Lee and Carlos Anchondo, "3 Trends to Shape Oil and Gas This Year," *E&E EnergyWire*, January 5, 2023, https://www.eenews.net/articles/3-trends-set-to-shape-oil-and-gas-this-year/.
[40] International Energy Agency, "Global Gas Security Review 2023" (IEA, July 18, 2023), https://www.iea.org/reports/global-gas-security-review-2023.
[41] V. Masson-Delmotte et al., "Global Warming of 1.5°C," An IPCC Special Report (The Intergovernmental Panel on Climate Change, 2018), https://www.ipcc.ch/sr15/.
[42] Coral Davenport, "Major Climate Report Describes a Strong Risk of Crisis as Early as 2040," *The New York Times*, October 7, 2018, https://www.nytimes.com/2018/10/07/climate/ipcc-climate-report-2040.html.
[43] E. Dinerstein et al., "A Global Deal for Nature: Guiding Principles, Milestones, and Targets," *Science Advances* 5, no. 4 (April 19, 2019): eaaw2869, https://doi.org/10.1126/sciadv.aaw2869.
[44] United Nations Development Program, "Climate Action Summit: A Joint Appeal from the UN System to the Secretary-General's Climate Action Summit," May 10, 2019, https://www.undp.org/content/undp/en/home/news-centre/speeches/2019/climate-action-summit.html.
[45] Intergovernmental Panel on Climate Change, "Climate Change 2021: The Physical Science Basis," Sixth Assessment Report, August 6, 2021, https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/.
[46] Matt McGrath, "Climate Change: IPCC Report Is 'Code Red for Humanity,'" *BBC News*, August 9, 2021, https://www.bbc.com/news/science-environment-58130705.

highly vulnerable.[47] Also in 2022, the third IPCC report, focused on mitigation, made clear that the window to averting runaway, irreversible climate impact is rapidly closing. To prevent global warming from exceeding 1.5° C—after which severe harm will accelerate—rising emissions must end before 2025. In a stark warning to fossil fuel investors the IPCC made clear that future fossil fuel assets will become stranded if governments do not act in accordance with the science.[48]

In 2021, the IEA released its roadmap for how net zero by 2050 could be reached. In it, the Agency made clear that the pathway to zero allows for no new fossil fuel production, and, indeed, that any further investments in fossil fuels—beyond what is already under contract—must cease. In this way, the IEA, departing from its past support of gas and oil development, has signaled its support for the conclusions of the IPCC and joined the global call to stop the expansion of fossil fuel extraction. (See footnote 2396.) To stay within a 1.5° C global warming scenario, methane emissions from fossil fuels must, according to the IEA, fall by around 75 percent between 2020 and 2030.[49] These findings were subsequently confirmed by the International Institute for Sustainable Development in a 2022 analysis concluding that any further development of new oil and gas field is incompatible with the 1.5° climate goal.[50]

Methane is a key driver of climate change and fracking is a key driver of methane

Third and more specifically, methane is now recognized as a chief agent of climate change as more accurate methods for calculating emissions inventories reveal that runaway methane emissions are negating recent declines in carbon dioxide emissions and undermining efforts to stabilize the climate. In New York State, a study using more comprehensive inventory approaches found that, as increased consumption of natural gas has replaced coal from 1995 to 2015, total greenhouse gas emissions did not fall but remained largely unchanged.[51] In a conclusion echoed by the IEA, the United Nations Environment Programme (UNEP) made clear in its Global Methane Assessment that any further expansion of natural gas infrastructure and usage is incompatible with limiting global warming to 1.5°C. (See footnote 1691.) This goal cannot be reached without slashing methane emissions by at least 40-45 percent by 2030 when compared with 2020 levels. (See footnote 1671.)

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[47] Intergovernmental Panel on Climate Change, "Climate Change 2022: Impacts, Adaptation and Vulnerability," Sixth Assessment Report, February 28, 2022, https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_FinalDraft_FullReport.pdf.

[48] Intergovernmental Panel on Climate Change, "Climate Change 2022: Mitigation of Climate Change," Sixth Assessment Report, April 4, 2022, https://report.ipcc.ch/ar6wg3/pdf/IPCC_AR6_WGIII_FinalDraft_FullReport.pdf.

[49] International Energy Agency, "Tackling Methane Emissions from Fossil Fuel Operations Is Essential to Combat Near-Term Global Warming," IEA.org, October 7, 2021, https://www.iea.org/news/tackling-methane-emissions-from-fossil-fuel-operations-is-essential-to-combat-near-term-global-warming.

[50] The International Institute for Sustainable Development, "Navigating Energy Transitions: Mapping the Road to 1.5°C" (International Institute for Sustainable Development, October 2022), https://www.iisd.org/system/files/2022-10/navigating-energy-transitions-mapping-road-to-1.5.pdf.

[51] Robert W. Howarth, "Methane Emissions from Fossil Fuels: Exploring Recent Changes in Greenhouse-Gas Reporting Requirements for the State of New York," *Journal of Integrative Environmental Sciences* 17, no. 3 (2020): 69–81, https://doi.org/10.1080/1943815X.2020.1789666.

As part of the Global Methane Pledge, launched in 2021 at COP26 climate summit in Glasgow, Scotland, more than 100 countries pledged to cut global methane emissions by a more modest 30 percent by 2030 from 2020 levels.[52] (China, Russia, India and Iran—all leading methane emitters—were not among the pact's signatories.) After briefly leveling off between 2000 and 2006, atmospheric methane levels have been surging upward ever since. In 2021, methane rose more than any other year on record, including 2020, which was also a record-breaking year.[53] Methane emissions remained high in 2022, despite rising energy prices that should have incentivized efforts to curtail leakage from, for example, non-emergency venting and flaring operations.[54]

The growing awareness that cutting methane from fossil fuels is a strong and necessary lever to slow climate change over the next two decades has roiled conversations about commitments to move forward with LNG projects. In British Columbia, for example, 17 new LNG export terminals are planned. However, a 2023 study shows that the methane emissions from just two of these projects would make impossible the province's legislated commitment to a 40 percent cut in emissions by 2030. This climate target allows no room for additional gas production or additional investments in LNG export infrastructure. Further, even if LNG exports displace coal burning abroad, the long-term commitment and sunk costs of additional natural gas infrastructure work against the needed energy transition. "This is true regardless of possible marginal reductions in its life cycle emissions gained through LNG terminal electrification and reduced methane losses during gas extraction, processing, transport and other upstream processes. This finding would remain true even if all upstream processes were electrified, as downstream emissions from gas combustion still represent the majority of gas's life cycle emissions."[55, 56]

At the same time, fracking within the European Union and the United Kingdom has largely languished.[57] As part of two symbolic, non-binding resolutions on methane in June and October 2021, the EU Parliament urged its member states to halt existing fracking operations and stop permitting new ones. "On the basis of the precautionary principle and the principle that preventive action should be taken, and taking into account the risks and the negative climate, environmental and biodiversity impacts involved in hydraulic fracturing for the extraction of unconventional hydrocarbons – not to authorise any new hydraulic fracturing operations in the

[52] Kate Abnett et al., "More than 100 Countries Join Pact to Slash Planet-Warming Methane Emissions," Reuters, November 2, 2021, https://www.reuters.com/world/middle-east/more-than-100-countries-join-pact-slash-planet-warming-methane-emissions-2021-11-02/.
[53] Raymond Zhong, "Methane Emissions Soared to a Record in 2021, Scientists Say," April 7, 2022, https://www.nytimes.com/2022/04/07/climate/methane-emissions-record.html.
[54] International Energy Agency, "Methane Emissions Remained Stubbornly High in 2022 Even as Soaring Energy Prices Made Actions to Reduce Them Cheaper than Ever," February 21, 2023, https://www.iea.org/news/methane-emissions-remained-stubbornly-high-in-2022-even-as-soaring-energy-prices-made-actions-to-reduce-them-cheaper-than-ever.
[55] Daniel Horen Greenford, "Burning Bridge: Debunking LNG as a Climate Solution" (David Suzuki Foundation, May 2023), https://davidsuzuki.wpenginepowered.com/wp-content/uploads/2023/05/Burning-Bridge-Debunking-LNG-as-a-Climate-Solution-Report.pdf.
[56] Nicholas Cunningham, "British Columbia LNG Drive May Wreck Climate Targets: Report," *Gas Outlook*, November 6, 2023, https://gasoutlook.com/analysis/british-columbia-lng-drive-may-wreck-climate-targets-report/.
[57] Shauna Corr, "Fracking Is Nearly Banned on the Island of Ireland," Buzz, February 16, 2022, https://www.buzz.ie/news/irish-news/fracking-nearly-banned-island-ireland-26204802.

EU and to halt all existing operations."[58] In the United Kingdom, a national moratorium on fracking was declared in 2019, overturned in April 2022, and then reinstated in October 2022. The fracking of two pre-existing shale gas wells in Lancashire, drilled prior to the 2019 national moratorium, had triggered earthquakes.[59, 60]

These conversations are taking place against rapidly changing norms on the disclosure of climate risks within the financial sector. In 2021, *S&P Global* reported that governments around the world have started to make climate-risk reporting mandatory instead of voluntary. Many policymakers have endorsed the framework of the Taskforce on Climate-related Financial Disclosures (TCFD) as a standardized disclosure framework. The financial sector has shown strong support for the TCFD, with the strongest support coming from Europe, Asia and North America, with the Institute for Energy Economics and Financial Analysis reporting that "finance is leaving oil and gas" and citing 66 globally significant financial institutions that have formally decided to restrict or terminate financial support for oil and gas drilling.[61, 62] In 2022, the Securities and Exchange Commission voted to issue draft rules that would require public companies to include climate-related disclosures for investors, including information about registrants' direct greenhouse gas emissions.[63]

Labor problems persist

A fourth drag on the ability of the U.S. fracking industry to continue its expansion is a persistent labor shortage. Fracking crews and truck drivers remain in short supply. Many employees and contractors relocated to other states and found other jobs during the industry contraction that followed the price crashes of 2020 and became wary of returning to jobs within a volatile

[58] European Parliament, "An EU Strategy to Reduce Methane Emissions," Texts Adopted (Strasbourg, October 21, 2021), https://www.europarl.europa.eu/doceo/document/TA-9-2021-0436_EN.html.
[59] BBC, "Fracking Ban Welcomed near UK's Only Shale Gas Wells," BBC.com, October 26, 2022, https://www.bbc.com/news/uk-england-lancashire-63404758.
[60] Ruth Hayhurst, "Cuadrilla Back in the Red, Value of Shale Gas Assets to Be Cut," *Drill or Drop*, June 23, 2023, https://drillordrop.com/2023/06/23/cuadrilla-back-in-the-red-value-of-shale-gas-assets-to-be-cut/.
[61] Gautam Naik, "Companies, Investors Face New Pressure from Compulsory Disclosure of Climate Risk," S&P Global, August 25, 2021, https://www.spglobal.com/esg/insights/companies-investors-face-new-pressure-from-compulsory-disclosure-of-climate-risk.
[62] Institute for Energy Economics and Financial Analysis, "Finance Is Leaving Oil and Gas," IIEFA.org, October 1, 2021, https://ieefa.org/finance-exiting-oil-and-gas/.
Institute for Energy Economics and Financial Analysis.
and Exchange Commission, "SEC Proposes Rules to Enhance and Standardize Climate-Related Disclosures for Investors," Press release, March 21, 2022, https://www.sec.gov/news/press-release/2022-46.

industry that relies on mass lay-offs to control costs when commodity prices plunge and investment dollars dwindle.[64, 65, 66, 67]

A 2021 survey of nearly 17,000 energy-industry recruiters, companies, and workers around the world found that applications per vacancy remained low even as oil and gas extraction activities ramped back up, with 43 percent of employees reporting a desire to leave the field altogether within the next five years, 56 percent of oil and gas workers reporting plans to pursue employment in the renewables sector, and 31 percent of recruiters identifying an aging, shrinking workforce as their biggest challenge.[68] The Russian invasion of Ukraine in 2022 that accelerated exports of oil and gas prompted a partial industry-wide recovery of jobs, but employment remains below 2019 levels, according to a 2023 Department of Energy report.[69]

At the professional level, the oil and gas industry is also struggling to attract workers. Since 2014, the number of college undergraduates pursuing studies in petroleum engineering has dropped by 75 percent over concerns about the climate crisis and job security, with many universities ending their petroleum engineering degree programs altogether.[70]

Drilling locations have become scarce

Depletion of drilling locations—what industry insiders call "limited inventory"—is a fifth impediment to further growth in the U.S. fracking industry. Companies are running out of new places to drill that do not interfere with the productivity of nearby pre-existing wells and are thus unable to respond to higher prices with higher rates of extraction.[71] Individual shale wells, which deplete more quickly than conventional wells, are pumping less oil and gas than predicted and require drillers to constantly expand their operations, increasing their capital costs, just to keep production level. Further, the industry has largely depleted its inventory of already drilled but

[64] Collin Eaton, "U.S. Frackers Fear Vaccine Mandate Will Worsen Worker Crunch," *Wall Street Journal*, September 30, 2021, https://www.wsj.com/articles/u-s-frackers-fear-vaccine-mandate-will-worsen-worker-crunch-11632994201.
[65] David Wethe, Sheela Tobben, and Josyana Joshua, "Ex-Fracker at Walmart Reveals One Risk to U.S. Oil Supply Growth," Bloomberg, October 21, 2021, https://www.bloomberg.com/news/articles/2021-08-26/ex-fracker-at-walmart-reveals-one-risk-to-u-s-oil-supply-growth.
[66] Geoffrey Morgan, "Rigs Sit Idle and Jobs Go Unfilled in Canadian Oilfields as Workers Walk Away from Volatile Job Market," *Financial Post*, January 4, 2022, https://financialpost.com/commodities/energy/oil-gas/rigs-sit-idle-and-jobs-go-unfilled-in-canadian-oilfields-as-worker-walk-away-from-volatile-job-market.
[67] Liz Hampton, "As Oil Prices Soar, U.S. Drillers Scramble to Find Sand for Fracking," Reuters, February 15, 2022, https://www.reuters.com/business/energy/oil-prices-soar-us-drillers-scramble-find-sand-fracking-2022-02-15/.
[68] "Energy Outlook 2021/22 Report" (Oil and Gas Jobs Search, n.d.), https://hiring.oilandgasjobsearch.com/energy-outlook-report-2021-22.
[69] U.S. Department of Energy, "United States Energy & Employment Report 2023" (U.S. Department of Energy, June 28, 2023), https://www.energy.gov/sites/default/files/2023-06/2023%20USEER%20REPORT-v2.pdf.
[70] Mari Novik and Collin Eaton, "Big Oil's Talent Crisis: High Salaries Are No Longer Enough," *Wall Street Journal*, August 6, 2023, https://www.wsj.com/articles/big-oils-talent-crisis-high-salaries-are-no-longer-enough-194545be.
[71] Derek Brower and Myles McCormick, "What the End of the US Shale Revolution Would Mean for the World," *Financial Times*, January 15, 2023, https://www.ft.com/content/60747b3b-e6ea-47c0-938d-af515816d0f1.

untapped wells, which it relied upon to lower costs and survive the pandemic-induced price crash in 2020.[72]

For these reasons, the Permian Basin, the most prolific U.S. oil and gas region, is now expected to plateau in 2025, far sooner than had been earlier predicted.[73, 74] While basin-wide productivity reached record highs in 2022, productivity per well has fallen, declining every month since September 2020.[75] The Bakken Shale in North Dakota is now branded as "mature," with the U.S. Geological Survey recently revising downward its estimate of the volumes of "technically recoverable" oil remaining in the Bakken by 40 percent from an earlier assessment and raising concerns among operators and investors about the feasibility of continued extraction and the productivity of existing wells.[76, 77, 78]

Thus, the apparent ongoing expansion of fracking activities in the United States, with oil and gas rig counts rising, is paradoxical. The current flurry of drilling is taking place within a struggling, not a flourishing, industry whose capital expenses are rising, production flattening, and which is no longer able to greatly increase the total amount oil and gas flowing out of the shale in response to higher prices.[79, 80]

With public opinion turned against fracking, many U.S. fracking-related projects have collapsed or are struggling

[72] Collin Eaton, "Shale Companies Drilling More, but Oil Output Growing Little," *Wall Street Journal*, March 21, 2022, https://www.wsj.com/articles/shale-companies-drilling-more-but-oil-output-growing-little-11647855002.
[73] Collin Eaton, "Oil Frackers Brace for End of the U.S. Shale Boom," *Wall Street Journal*, February 3, 2022, https://www.wsj.com/articles/fracking-oil-prices-shale-boom-11643824329.
[74] Javier Blas, "Wall Street Is Finally Going to Make Money off the Permian," *Washington Post*, April 24, 2023, https://www.washingtonpost.com/business/energy/2023/04/24/higher-oil-prices-means-wall-street-s-shale-investments-will-finally-pay-off/aab5b38c-e2f6-11ed-9696-8e874fd710b8_story.html.
[75] Stephanie Kelly, "U.S. Permian Oil Output to Hit Record in December, but Gains Are Slow," Reuters, November 14, 2022, https://www.reuters.com/business/energy/us-permian-oil-production-due-rise-dec-record-eia-2022-11-14/.
[76] U.S. Geological Survey, "Assessment of Undiscovered Continuous Oil Resources in the Bakken and Three Forks Formations of the Williston Basin Province, North Dakota and Montana, 2021," National and Global Petroleum Assessment (U.S. Geological Survey, December 15, 2021), https://pubs.usgs.gov/fs/2021/3058/fs20213058.pdf.
[77] Adam Willis, "Bakken Oil Play Now Branded 'mature' as Industry Appetites Shrink in North Dakota," Inforum, February 14, 2022, https://www.inforum.com/news/bakken-oil-play-now-branded-mature-as-industry-appetites-shrink-in-north-dakota.
[78] Benoît Morenne, "Frackers Say Oil Production Slowing in the Shale Patch," *The Wall Street Journal*, November 6, 2022, https://www.wsj.com/articles/frackers-say-oil-production-slowing-in-the-shale-patch-11667743226?st=9zg384j85s47sd9.
[79] Scott Disavino, "U.S. Drillers Add Oil and Gas Rigs for Record 16th Month -Baker Hughes," Reuters, November 24, 2021, https://www.reuters.com/business/energy/us-drillers-add-oil-gas-rigs-record-16th-month-baker-hughes-2021-11-24/.
[80] Derek Brower and Myles McCormick, "Top Shale Oil Boss Warns US Can't Replace Any Russia Shortfall," *Financial Times*, March 4, 2022, https://www.ft.com/content/1b517f6d-9056-41ba-9d1e-324e495b5041?

The sixth trend working against growth in the fracking industry: public opinion has turned decidedly against fracking.[81, 82] Public polling shows more Americans now oppose fracking than support it, including more than 50 percent of registered voters in Pennsylvania.[83] By 2021, only 31 percent of Pennsylvania voters wanted fracking to continue in the state, while 55 percent wanted it to end as soon as possible or be phased out over time.[84]

Public pressure on state governments to prohibit or limit fracking—and, more generally, to reduce their dependency on fossil fuels in order to address climate change—has intensified. Protests and legal challenges against pipelines carrying the products of fracking have spread and become more sophisticated. Some elected officials and government bodies, both in the United States and abroad, have begun to take steps in response to increasing public alarm at the accelerating climate crisis and the role that fracking plays in driving it.

Several high-profile projects have been canceled or are entangled in complex regulatory troubles. In all cases, they faced overwhelming, well-organized public opposition.

In May 2020, New York's then-Governor Andrew Cuomo blocked a permit for the **Williams Northeast Supply Enhancement pipeline**, which would have ferried fracked gas from Pennsylvania, through New Jersey, across the New York Harbor, and into Long Island. In so doing, he cited the state's climate legislation. (However, in 2021, FERC approved William's request for a two-year extension of the certificate to construct this pipeline.[85] In June 2023, Williams asked FERC for another extension of three years.)

Signed into law in July 2019, New York's Climate Leadership and Community Protection Act mandates, among other benchmarks, an economy-wide emissions reduction of 85 percent by 2050.

The state's Climate Act, which specifically requires the state to reach 70 percent carbon-free electricity by 2030 and 100 percent by 2040, was instrumental in the denial of permits to multiple proposed fracked gas infrastructure projects in the state.[86] These include a fracked-gas power plant in Queens (the **NRG project**) and the proposed expansion of the **Danskammer gas-**

[81] Art Swift, "Americans Split on Support for Fracking in Oil, Natural Gas," Gallup, March 23, 2015, https://news.gallup.com/poll/182075/americans-split-support-fracking-oil-natural-gas.aspx.
[82] Seth Borenstein, Nicholas Riccardi, and Hannah Fingerhut, "AP-NORC Poll: 64% Disapprove of Trump's Climate Change Views," Associated Press, September 12, 2019, https://apnews.com/article/82e8e6fd7b43436cbf5208ee1558d6b1.
[83] Ben German, "Poll: A Majority of Pennsylvanians Oppose Fracking," Axios, August 10, 2020, https://www.axios.com/pennsylvania-fracking-poll-4e215784-4838-4120-b9f3-29147742f5fb.html.
[84] Eric de Place, "Pennsylvania Voters Support a Serious Crackdown on Fracking Operations" (Ohio River Valley Institute, July 29, 2021), https://ohiorivervalleyinstitute.org/dfp-poll/.
[85] Reuters Staff, "U.S. Gives Williams More Time to Build Pennsylvania-NY Natgas Line," Reuters, May 20, 2021, https://www.reuters.com/business/energy/us-gives-williams-more-time-build-pennsylvania-ny-natgas-line-2021-05-20/.
[86] New York State Governor's Office, "Governor Cuomo Executes the Nation's Largest Offshore Wind Agreement and Signs Historic Climate Leadership and Community Protection Act," press release, July 18, 2019, https://www.governor.ny.gov/news/governor-cuomo-executes-nations-largest-offshore-wind-agreement-and-signs-historic-climate.

fired power plant in the Hudson River Valley.[87, 88] Separately, in 2021, the **Gowanus Generating Station** on the Brooklyn waterfront withdrew its application to repower its turbines with natural gas and announced it will be pursuing renewable energy and energy storage options.[89] In 2022, National Grid abandoned its plans for the **Albany Loop**, a fracked gas pipeline across the Hudson River, a project that, citizen groups argued, was incompatible with the state's Climate Act.[90] In March 2023, the Public Service Commission denied National Grid's request to build LNG vaporizers in North Brooklyn, a project intended to increase capacity of the North Brooklyn Pipeline during peak periods of demand.[91] In April 2023, National Grid officially withdrew its application.

The fate of **National Grid's North Brooklyn Pipeline**, which would carry fracked gas from Brownsville to Bushwick through low-income communities of color, is still in play. In 2021, the U.S. Environmental Protection Agency (EPA) announced it would investigate the state's decision to approve the pipeline in response to a federal civil rights complaint, and the U.S. Department of Transportation likewise launched a civil rights probe into the pipeline's approval process.[92, 93] The completion of the pipeline, now partially operational, has been delayed by widespread community opposition and a lawsuit against National Grid and New York State.[94]

In 2021, New York City Council passed a local law, signed by the mayor, that bans the burning of fossil fuels, including natural gas, in all new buildings, with buildings of all sizes to be constructed fully electric by 2027.[95] In May 2023, New York became the first state to pass a law banning fossil fuels, including natural gas hookups, in most new buildings. Specifically, the law

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[87] Daniel Whitehead, "Notice of Denial of Title V Air Permit, DEC ID: 2-6301-00191/00014" (New York State Department of Environmental Conservation, October 27, 2021), https://www.dec.ny.gov/docs/administration_pdf/nrgastoriadecision10272021.pdf.

[88] Daniel Whitehead, "Notice of Denial of Title V Air Permit, DEC ID: 3-3346-00011/00017" (New York State Department of Environmental Conservation, October 27, 2021), https://www.dec.ny.gov/docs/permits_ej_operations_pdf/danskammerdecision102721.pdf.

[89] Shant Shahrigian, "Power Company Scraps Plan for Natural Gas Turbines in Gowanus, Brooklyn," *New York Daily News*, December 26, 2021, https://www.nydailynews.com/news/politics/new-york-elections-government/ny-gowanus-astoria-generating-company-natural-gas-20211226-dnph2e5arjhynargdzsdjh6s54-story.html.

[90] Larry Rulison, "National Grid Scraps Plan to Build Pipeline across Hudson," *Times Union*, January 28, 2022, https://www.timesunion.com/business/article/National-Grid-scraps-plan-to-build-pipeline-16813176.php.

[91] Brooklyn Eagle Staff, "NY Rejects National Grid's Fracked Gas Vaporizers in Greenpoint," *Brooklyn Daily Eagle*, March 16, 2023, https://brooklyneagle.com/articles/2023/03/16/ny-rejects-national-grids-fracked-gas-vaporizers-in-greenpoint/.

[92] Samantha Maldonado, "Feds Launch a Second Civil Rights Investigation Into Brooklyn Gas Pipeline," *The City*, February 9, 2022, https://www.thecity.nyc/environment/2021/11/19/22792264/brooklyn-gas-pipeline-new-federal-civil-rights-investigation.

[93] Brooklyn Eagle Staff, "EPA to Investigate State's Approval of North Brooklyn Gas Pipeline," *Brooklyn Eagle*, October 25, 2021, https://brooklyneagle.com/articles/2021/10/25/epa-to-investigate-states-approval-of-north-brooklyn-gas-pipeline/.

[94] "Sane Energy Project, Cooper Park Resident Council, Inc, Christine Facella, Eric Kun, and William Vega, Petitioners, versus, New York State Department of Environmental Conservation and Brooklyn Union Gas Company D/B/A National Grid" (Supreme Court of the State of New York County of Queens, March 18, 2021), https://static1.squarespace.com/static/591df0576b8f5b5eb0ae5849/t/6053a4fd4ac0744b261a98b7/1616094461803/Petition+-+FINAL+3.18_PDF.pdf.

[95] "Mayor de Blasio Signs Landmark Bill to Ban Combustion of Fossil Fuels in New Buildings," NYC: The Official Website of the City of New York, December 22, 2021, https://www1.nyc.gov/office-of-the-mayor/news/852-21/mayor-de-blasio-signs-landmark-bill-ban-combustion-fossil-fuels-new-buildings.

requires all-electric heating and cooking new buildings less than seven stories by 2026 and, for taller buildings, by 2029.[96]

The **Jordan Cove LNG plant** in Oregon folded after a 15-year campaign of public opposition (see page 75). Similarly, plans for the 124-mile **Constitution pipeline,** which would have carried fracked gas from Susquehanna County, Pennsylvania to Schoharie County, New York, were abandoned in 2020 after the developer cited regulatory difficulties obtaining permits and diminishing returns on investment.[97] Further, five acres of forested land seized by eminent domain to make way for that pipeline were returned to the family who owned them after a federal court vacated the taking.[98]

The 116-mile **PennEast pipeline project**, which would have ferried fracked gas from Luzerne County, Pennsylvania to Mercer County, New Jersey was blocked after New Jersey denied key water permits. PennEast's cancellation in 2021 took place just months after the U.S. Supreme Court had ruled in favor of the pipeline company over eminent domain issues.[99]

In April 2023, the proposed **Gibbstown LNG terminal** in New Jersey was denied a federal permit by the Pipeline and Hazardous Materials Safety Administration (PHMSA) and continues to face stiff public opposition and other regulatory uncertainties.[100] According to the proposal, LNG would be delivered to the export terminal by truck and train from a new liquefaction plant

[96] Anna Phillips, "N.Y. Ditches Gas Stoves, Fossil Fuels in New Buildings in First Statewide Ban in U.S.," *The Washington Post*, May 3, 2023, https://www.washingtonpost.com/climate-environment/2023/05/03/newyork-gas-ban-climate-change/.
[97] Scott Blanchard, "Constitution Pipeline Project Ends as Builder Cites 'Diminished' Return on Investment," State Impact Pennsylvania, February 25, 2020, https://stateimpact.npr.org/pennsylvania/2020/02/25/constitution-pipeline-project-ends-as-builder-cites-diminished-return-on-investment/.
[98] Susan Phillips, "Family That Lost Hundreds of Trees to Failed Pipeline Project Settles with Company, Gets Land Back," State Impact Pennsylvania, July 3, 2020, https://stateimpact.npr.org/pennsylvania/2020/07/03/family-lost-hundreds-of-trees-to-failed-pipeline-project-settles-with-company-gets-land-back/.
[99] Susan Phillips, "PennEast Cancels Natural Gas Pipeline Project; Cites Lack of Environmental Permits from N.J.," WHYY, September 27, 2021, https://whyy.org/articles/penneast-cancels-natural-gas-pipeline-project-cites-lack-of-environmental-permits-from-n-j/.
[100] Zoë Read, "Gibbstown LNG by Rail Proposal Hits Another Roadblock," WHYY, April 26, 2023, https://whyy.org/articles/gibbstown-lng-rail-proposal-new-jersey-pennsylvania-natural-gas/.

planned for Pennsylvania's Bradford County as part of a plan approved by the Delaware River Basin Commission in 2020.[101, 102, 103, 104, 105]

To make that route possible, the Trump Administration issued a Special Permit for the transport of LNG by rail over 200 miles from Bradford County to Gibbstown.[106] Subsequent to that, PHMSA amended regulations to allow for the nationwide bulk transport of highly explosive LNG by rail tank cars (the "Trump Rule"). This rule upended the longstanding federal ban on the transport of LNG by rail. Despite a legal challenge filed in federal court by fourteen states and the District of Columbia and environmental organizations,[107] the new rule took effect in August 2020.[108, 109] However, after two years of no use, the Special Permit expired in November 2021, and an application for a renewal of that permit is what PHMSA recently denied. The potential impacts to public safety and greenhouse gas emissions have been further documented since the issuance of the Special Permit was rushed through. The Biden Administration proposed a federal rulemaking to suspend the "Trump Rule" but missed the April 2023 deadline to do so and pushed the date out until next year.[110, 111]

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[101] Andrew Maykuth, "The 'hidden' Plan to Remake an Old Dynamite Factory near Philly into a Major Gas Export Terminal," *The Philadelphia Inquirer*, June 9, 2020, sec. Business, https://www.inquirer.com/business/energy/philadelphia-lng-export-terminal-delaware-river-fortress-20190609.html.
[102] Andrew Maykuth, "Contentious Plan to Remake N.J. Dynamite Plant into Shale-Gas Export Terminal Is Approved," *The Philadelphia Inquirer*, June 12, 2019, sec. Business, https://www.inquirer.com/business/lng-export-terminal-philadelphia-repauno-fortress-approved-20190612.html.
[103] Jon Hurdle, "DRBC Confirms Plan to Build LNG Export Terminal at New South Jersey Port," *NJ Spotlight News*, June 12, 2019, sec. Energy & Environment, https://www.njspotlight.com/2019/06/19-06-11-drbc-confirms-plan-to-build-lng-export-terminal-at-new-south-jersey-port/.
[104] Yale Environment 360, "Controversy Mounts over Proposed LNG Export Facility on the Delaware River," *E360 Digest*, October 22, 2020, https://e360.yale.edu/digest/controversy-mounts-over-proposed-lng-export-facility-on-the-delaware-river.
[105] Andrew Maykuth, "Contentious N.J. River Terminal to Export Fracked Pa. Natural Gas Gets Final Approval," *The Philadelphia Inquirer*, December 9, 2020, sec. Business, https://www.inquirer.com/business/lng-port-delaware-river-repauno-drbc-gibbstown-approved-20201209.html.
[106] Pipeline Hazardous Materials Safety Administration, "Special Permit DOT-SP 20534" (U.S. Department of Transportation, December 5, 2019), https://www.phmsa.dot.gov/safe-transportation-energy-products/dot-20534-pdf.
[107] "Petition for Review in the United States Court of Appeals for the District Of Columbia Circuit Sierra Club, Center for Biological Diversity, Clean Air Council, Delaware Riverkeeper Network, Environmental Confederation of Southwest Florida, and Mountain Watershed Association Petitioners, v. United States Department of Transportation, et Al.," August 18, 2020, https://earthjustice.org/sites/default/files/files/petition_for_review_final.pdf.
[108] "Hazardous Materials: Notice of Issuance of Special Permit Regarding Liquefied Natural Gas," Notice (National Archives and Records Administration, December 11, 2019), https://www.federalregister.gov/documents/2019/12/11/2019-26614/hazardous-materials-notice-of-issuance-of-special-permit-regarding-liquefied-natural-gas.
[109] Hannah Chinn, "No 'Bomb Trains': 14 States Aim to Take New Rule on LNG Transport off the Rails," State Impact Pennsylvania, August 21, 2020, https://stateimpact.npr.org/pennsylvania/2020/08/21/no-bomb-trains-14-states-aim-to-take-new-rule-on-lng-transport-off-the-rails/.
[110] Pipeline and Hazardous Materials Safety Administration, "Hazardous Materials: Suspension of HMR Amendments Authorizing Transportation of Liquefied Natural Gas by Rail" (Federal Register, November 8, 2021), https://www.federalregister.gov/documents/2021/11/08/2021-23132/hazardous-materials-suspension-of-hmr-amendments-authorizing-transportation-of-liquefied-natural-gas.
[111] Dana DiFilippo, "Feds Delay Rewriting Rail Rule for Gas Transport, Irking Environmentalists," *New Jersey Monitor*, March 14, 2023, https://newjerseymonitor.com/2023/03/14/feds-delay-rewriting-rail-rule-for-gas-transport-irking-environmentalists/.

New Fortress Energy, one of Gibbstown project's developers, also owns the Shannon LNG import terminal in Ireland. Quashed several times between 2015 and 2019, this project was revived again in 2021, continued to face fierce public resistance, and was, strikingly, not listed as a Project of Common Interest by the European Commission in November 2021.[112] In September 2023, the Irish government denied New Fortress a permit on the basis that it contradicted Ireland's climate goals.[113]

Also in September 2023, Indigenous tribes in Wisconsin, Minnesota, and Michigan demanded that the federal government deny approval for construction of a new natural gas power plant near the Enbridge Energy pipeline hub near Lake Superior, calling the project "unconscionable" in the face of climate change.[114]

And yet fracking-related projects are still moving forward

In spite of rising public opposition and faltering long-term prospects, the fracking industry has been able to attract private equity funds and retains a firm and corrupting grip on the political process.[115] As of February 2022, a total of 119 oil pipelines and 477 gas pipelines were under development around the world in spite of the fact that 90 percent of the global economy is under a net-zero pledge and despite warnings by both the IPCC and the IEA that exploiting new oil and gas fields is incompatible with a net zero goal, and "given the rapid decline of fossil fuels, significant investments in new oil and gas pipelines are not needed."[116] A 2023 analysis of the net-zero strategies of the world's four largest oil companies found that "no major's decarbonization pathway encompasses a business model transformation away from fossil fuels."[117]

Here is a sampling of some of the fracking-related projects and initiatives around the world that are still moving forward or still in play:

United States. As of this writing, the United States is set to double its LNG export capacity in the next five years and is on track to approve three major LNG export facilities, which would be a single-year record. In addition to Sempra's Port Arthur terminal, they include Venture Global's

[112] European Commission, "Annex VII: The Union List of Projects of Common Interest ('Union List')," November 19, 2021, https://ec.europa.eu/energy/sites/default/files/fifth_pci_list_19_november_2021_annex.pdf.
[113] Senan Molony, Caroline O'Doherty, and Stephen Fernane, "Shannon LNG: €650m Gas Facility Refusal No Threat to Jobs or Energy Security, Eamon Ryan Insists," *Irish Independent*, September 15, 2023, https://www.independent.ie/irish-news/shannon-lng-650m-gas-facility-refusal-no-threat-to-jobs-or-energy-security-eamon-ryan-insists/a1564144302.html.
[114] Associated Press, "Indigenous Tribes Urge Federal Officials to Deny Loan Request for Superior Natural Gas Plant," *MPR News*, September 12, 2023, https://www.mprnews.org/story/2023/09/12/indigenous-tribes-urge-federal-officials-to-deny-loan-request-for-superior-natural-gas-plant.
[115] Hiroko Tabuchi, "Private Equity Funds, Sensing Profit in Tumult, Are Propping Up Oil," *New York Times*, October 13, 2021, https://www.nytimes.com/2021/10/13/climate/private-equity-funds-oil-gas-fossil-fuels.html.
[116] Nick Ferris, "Weekly Data: One Million Kilometres of New Fossil Pipelines Poses Stranded Asset Risk," Energy Monitor, February 14, 2022, https://www.energymonitor.ai/finance/risk-management/weekly-data-one-million-kilometres-of-proposed-fossil-fuel-pipelines-poses-stranded-asset-risk.
[117] Gregory Trencher, Mathieu Blondeel, and Jusen Asuka, "Do All Roads Lead to Paris?: Comparing Pathways to Net-Zero by BP, Shell, Chevron and ExxonMobil," *Climatic Change* 176, no. 7 (July 2023): 83, https://doi.org/10.1007/s10584-023-03564-7.

Plaquemine terminal in Louisiana and NextDecade's Rio Grande LNG project in Brownsville, Texas.[118, 119] In April 2023, FERC re-approved Rio Grande LNG after years of public opposition and legal challenges by municipalities, indigenous organizations, and shrimp fishermen and after a federal court remanded FERC's original 2021 approval of this project. In July 2023, NextDecade announced it had secured funding sufficient to begin construction.[120]

In addition, New Fortress Energy announced in June 2023 that it intended to reapply for permits to construct an $800 million LNG plant in Bradford County, Pennsylvania after ceasing construction there three years earlier in the wake of public opposition and legal challenges.[121]

In January 2023, New Fortress Energy secured a ten-year contract to operate and manage all of Puerto Rico's power plants, a deal that is widely seen as undermining the territory's transition to renewable energy.[122, 123] New Fortress also supplies the island with LNG and owns an LNG import terminal in San Juan that was built without authorization from FERC.[124]

The $6.2 billion Mountain Valley Pipeline, which lost key regulatory permits in 2021 and 2022, was given new momentum in 2023 when the debt ceiling deal between Congress and the White House removed many of these obstacles and required its approval.[125, 126, 127, 128] In June 2023, as mandated by the Fiscal Responsibility Act, the Army Corps of Engineers granted a Clean Water

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[118] Scott Disavino, "US LNG Project Approvals on Track for Record New Volumes," *Reuters*, June 23, 2023, https://www.reuters.com/business/energy/us-lng-project-approvals-track-record-new-volumes-2023-06-23/.
[119] Debra K. Rubin, Mary B. Powers, and Michael Dumiak, "Living With LNG: Can More Gas Infrastructure and Climate Goals Coexist?," *Engineering News-Record*, February 16, 2023, https://www.enr.com/articles/55932-living-with-lng-can-more-gas-infrastructure-and-climate-goals-coexist.
[120] Dylan Baddour, "Developer Confirms Funding For Massive Rio Grande Gas Terminal," *Inside Climate News*, July 12, 2023, https://insideclimatenews.org/news/12072023/rio-grande-lng-export-terminal-brownsville/.
[121] Frank Wilkes Lesnefsky, "Developer Revives Efforts to Ship Liquefied Natural Gas through Abingtons and Other Communities in Lackawanna, Luzerne and Wyoming Counties," *The Citizen's Voice*, July 2, 2023, https://www.citizensvoice.com/news/developer-revives-efforts-to-ship-liquefied-natural-gas-through-abingtons-and-other-communities-in-lackawanna/article_fd49b2cb-2dee-51a0-bed4-ca6954f11a61.html.
[122] Jim Wyss, "New Fortress Subsidiary Wins Puerto Rico Power Plants Bid," *Bloomberg Law*, January 25, 2023, https://news.bloomberglaw.com/environment-and-energy/new-fortress-subsidiary-wins-puerto-rico-power-plants-bid-1.
[123] Nicholas Kusnetz, "Puerto Rico Hands Control of Its Power Plants to a Natural Gas Company," *Inside Climate News*, January 26, 2023, https://insideclimatenews.org/news/26012023/puerto-rico-hands-control-of-its-power-plants-to-a-natural-gas-company/.
[124] Eliván Martínez Mercado, "New Fortress Breaches Contract on Gas Supply, Puerto Rico's Government Allows It," *Centro de Periodismo Investigativo*, September 8, 2022, https://periodismoinvestigativo.com/2022/09/new-fortress-breaches-contract-on-gas-supply-puerto-ricos-government-allows-it/.
[125] Laurence Hammack, "Mountain Valley Hits Another Snag in Its Pipeline Plans," *Roanoake Times*, February 11, 2022, https://roanoke.com/news/local/mountain-valley-hits-another-snag-in-its-pipeline-plans/article_b4daa376-8b69-11ec-a5b3-e34446874bba.html.
[126] Laurence Hammack, "Legal Fights Continue over the Mountain Valley Pipeline," *Martinsville Bulletin*, January 8, 2022, https://martinsvillebulletin.com/news/state-and-regional/legal-fights-continue-over-the-mountain-valley-pipeline/article_ffc34322-2243-5d16-afbd-5452abd70ca8.html.
[127] Sarah Vogelsong, "Chickahominy Pipeline Will 'Press Pause' on Project Crossing Five Central Va. Counties," *Virginia Mercury*, February 14, 2022, https://www.virginiamercury.com/blog-va/chickahominy-pipeline-will-press-pause-on-project-crossing-five-central-va-counties/.
[128] Charlie Paullin, "Mountain Valley Pipeline Approvals OKed as Part of Debt Ceiling Deal," *Virginia Mercury*, June 2, 2023, https://www.virginiamercury.com/2023/06/02/mountain-valley-pipeline-approvals-oked-as-part-of-debt-ceiling-deal/.

Action Section 404 permit, which it had previously withheld because the pipeline project was lacking an Endangered Species Act opinion from the U.S. Fish and Wildlife Service. Stream-crossing authorizations are needed to complete the pipeline's construction, and the granting of this key permit now allows the pipeline project to trench through hundreds of streams along its path.[129] In July 2023, the U.S. Supreme Court lifted a lower court's temporary halt to further construction of the pipeline, which had been on hold since 2021.[130]

The Federal Energy Regulatory Commission reviews proposed LNG projects, as directed by the Natural Gas Act. However, this legislation offers no guidance for what should be included in a cost-benefit analysis for an LNG export terminal and tilts toward approval. In May 2023, 44 members of Congress called for a review of how the Biden administration handles LNG exports and more guidance for FERC decision-making. For example, it is currently not clear if, under the Natural Gas Act, FERC can even consider the climate impacts of natural gas after it has been exported.[131] In September 2023, FERC voted to approve the expansion of Sempra's Port Author LNG liquefaction terminal in Jefferson County, Texas and Venture Global's Calcasieu Pass LNG export terminal in Cameron Parish, Louisiana.[132]

As of this writing, 24 states with Republican-controlled legislatures have passed laws blocking municipalities from banning or disincentivizing natural gas by, for example, enacting building codes that would mandate electrification of new buildings or phase out gas use in new or existing buildings.[133] This wave of state laws prohibits the very pathway that the IEA has called for and identified as the most viable route to net-zero emissions by 2050. In April 2023, a new state law in Ohio relabeled fracked gas as "green energy" and requires fracking under state-owned land, including state parks.[134] Also in April 2023, a federal court overturned Berkeley, California's 2019 prohibition on natural gas lines in new buildings on the grounds that the ordinance is pre-empted by a federal law. This ruling raises questions about 75 other California cities with municipal gas bans and the possibility that they could likewise see their own ordinances overturned.[135] In August 2023, California's Energy Commission and the State Water Resources

[129] "Department of the Army Permit," June 23, 2023, https://www.energy.senate.gov/services/files/15A0ED14-182D-4D73-88DB-475C15999E86.
[130] Robert Barnes and Rachel Weiner, "Supreme Court Clears the Way for Pipeline Construction Favored by Manchin," *Washington Post*, July 27, 2023, https://www.washingtonpost.com/politics/2023/07/27/supreme-court-mountain-valley-pipeline/.
[131] Miranda Willson, "LNG Is Surging. Can FERC Reviews Keep Up?," *E&E Energy Wire*, May 11, 2023, https://www.eenews.net/articles/lng-is-surging-can-ferc-reviews-keep-up/.
[132] Maxine Joselow, "FERC Approves Gas Projects despite Calls for Fossil Fuel Phaseout," September 22, 2023, https://www.washingtonpost.com/politics/2023/09/22/ferc-approves-gas-projects-despite-calls-fossil-fuel-phaseout/.
[133] Maxine Joselow and Vanessa Montalbano, "Red States Are Blocking Blue Cities from Setting Climate Policies," *The Washington Post*, June 13, 2023, https://www.washingtonpost.com/politics/2023/06/13/red-states-are-blocking-blue-cities-setting-climate-policies/.
[134] Jessie Balmert, "Ohio Lawmakers May Require Fracking under State Land, Label Natural Gas 'Green,'" *Cincinnati Enquirer*, December 7, 2022, https://www.cincinnati.com/story/news/politics/2022/12/07/ohio-lawmakers-may-require-fracking-under-state-land-label-natural-gas-green/69707982007/.
[135] Lylla Younes, "First Natural Gas Ban in the US Just Got Shot Down," Route Fifty, April 20, 2023, https://www.route-fifty.com/infrastructure/2023/04/first-natural-gas-ban-us-just-got-shot-down/385458/.

Control Board granted a three-year shutdown extension to three gas-fired powered power plants (in Huntington Beach, Long Beach, and Oxnard) that had been slated for closure.[136]

Canada. Located on the traditional territory of the Haisla Nation, LNG Canada in Kitimat on the British Columbian coast is a joint venture led by Chevron and represents Canada's first terminal for exporting natural gas. Construction is underway, with LNG shipments to Asia projected to begin in 2025. Four other LNG projects in British Columbia have been proposed, including the long-delayed, over-budget Woodfibre LNG export terminal in Squamish. Projecting a 2027 start-up date, Woodfibre seeks to install a new high-pressure gas pipeline to connect with the Westcoast Transmission System pipeline that carries fracked gas from shale fields in northeastern British Columbia to the southwestern coast. Woodfibre is sited on Howe Sound, which was designated a UNESCO biosphere reserve in 2021.[137, 138, 139]

Europe. To the surprise of many, a draft of the EU's "green energy taxonomy" released in December 2021 labeled natural gas a transitional fuel and included natural gas projects in its list of investments that it considers sustainable. A technical document that enumerates for the financial sector the investments considered green by the EU bloc, the taxonomy was endorsed by the European Commission in February 2022 over objections that it would lead to the construction of more gas-fired power plants.[140]

In 2021, the French utility Engie, of which the French government is a shareholder, signed a secretive, 11-year sale and purchase agreement with Texas-based Cheniere Energy to import LNG from its Corpus Christi terminal. This deal represents an about-face for Engie, which, in 2020, pulled out of a 20-year, $7 billion contract with NextDecade's Rio Grande LNG export terminal in Brownsville, Texas, citing concerns about greenhouse gas emissions in Permian Basin fracking operations.[141, 142] In June 2023, the French oil major, TotalEnergies announced it would be investing in the Rio Grande LNG export plant.[143]

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[136] Sammy Roth, "Despite Climate Goals, California Will Let Three Gas Plants Keep Running," *Los Angeles Times*, August 15, 2023, https://www.latimes.com/environment/newsletter/2023-08-15/despite-climate-goals-california-will-let-three-gas-plants-keep-running-boiling-point.
[137] Brent Jang, "LNG Canada CEO Bullish on Expansion of Export Terminal," *The Globe and Mail*, July 6, 2023, https://www.theglobeandmail.com/business/article-lng-canada-ceo-bullish-on-expansion-of-export-terminal/.
[138] Nicholas Cunningham, "Woodfibre LNG in Canada Threatens UNESCO Reserve," *Gas Outlook*, September 12, 2023, https://gasoutlook.com/analysis/woodfibre-lng-in-canada-threatens-unesco-reserve/.
[139] Nicholas Cunningham, "Canada's Woodfibre LNG Rests on Shaky Financial Prospects," *Gas Outlook*, September 14, 2023, https://gasoutlook.com/analysis/woodfibre-lng-in-canada-rests-on-shaky-financial-prospects/.
[140] Joe Lo, "European Commission Endorses Fossil Gas as 'Transition' Fuel for Private Investment," https://www.climatechangenews.com/2022/02/02/european-commission-endorses-fossil-gas-transition-fuel-private-investment/, February 2, 2022, https://www.climatechangenews.com/2022/02/02/european-commission-endorses-fossil-gas-transition-fuel-private-investment/.
[141] Harry Weber, "Cheniere to Supply LNG from Texas Export Facility under New Deal with France's Engie," S&P Global, November 11, 2021, https://www.spglobal.com/platts/en/market-insights/latest-news/lng/111121-cheniere-to-supply-lng-from-texas-export-facility-under-new-deal-with-frances-engie.
[142] Les Amis de la Terre France, "Engie Secretly Signs a New Contract to Import Fracked Gas in France," amisdelaterre.org, December 3, 2021, https://www.amisdelaterre.org/communique-presse/mustang-contract-engie-secretly-signs-a-new-contract-to-import-fracked-gas-in-france/.
[143] Nicholas Cunningham, "TotalEnergies Invests in Controversial Rio Grande LNG," *Gas Outlook*, June 15, 2023, https://gasoutlook.com/news/totalenergies-invests-in-controversial-rio-grande-lng/.

Germany has been both rapidly building out LNG import infrastructure to increase its ability to buy natural gas from the United States and rapidly investing LNG export infrastructure in the United States. In 2022, Germany entered an agreement with the Australian oil and gas company Woodside to acquire LNG from the Corpus Christi LNG Project in Texas.[144] In January 2023, the German finance minister called for overturning Germany's domestic fracking ban, which has been in place since 2017.[145]

Australia. In 2022, Woodside's LNG terminal near Perth in Western Australia received final approval. One of the largest oil and gas projects in the nation, the $16.5 billion LNG export facility is projected to go online in 2026.[146] As of April 2023, however, it remained stalled due to demand uncertainty.[147]

Mexico. Five new LNG projects have been proposed for Mexico's Pacific Coast as the region has been targeted by the gas industry to serve as a corridor for exporting gas from the United States' Permian Basin to Asia. In 2021, one year after receiving the final permit from the government of Mexico to construct an LNG export terminal on the Pacific coast of Baja California, Sempra announced plans to begin building a second LNG export plant in the Mexican port city of Topolobampo on the Gulf of California.[148, 149] In December 2022, both plants received authorization from the U.S. Department of Energy to re-export LNG from U.S.-sourced natural gas when they become operational.[150] In July 2023, Mexico Pacific announced a 20-year purchase agreement with ConocoPhillips to buy LNG from its proposed Saguaro Energia LNG export terminal in Puerto Libertad.[151]

Argentina. Fracking activity in Argentina's Vaca Muerta Basin, which is the world's second-largest shale gas deposit and fourth-largest shale oil reserve, has been booming since 2021 as pandemic lockdowns eased, demand rose, and pricing structures encouraged expanded drilling for gas and oil. This spike in fracking operations is the result of a years-long policy process to incentivize and subsidize further oil and gas exploration in a nation where half of the energy mix is natural gas, of which 45 percent is extracted through fracking, and fracking is seen by political

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[144] Woodside Energy Ltd., "Woodside and RWE Sign Agreement for Mid-Term LNG Supply," Press Release, December 20, 2018, https://www.woodside.com.au/docs/default-source/media-releases/woodside-and-rwe-sign-agreement-for-mid-term-lng-supply.pdf.
[145] Charles Kennedy, "German Finance Minister Calls For Reverse Of Fracking Ban," OilPrice.com, January 2, 2023, https://oilprice.com/Energy/Natural-Gas/German-Finance-Minister-Calls-For-Reverse-Of-Fracking-Ban.html.
[146] Rebecca Turner, "Woodside's Controversial Scarborough LNG Project Gets Final Approval amid Climate Warnings," *ABC News*, April 6, 2022, https://www.abc.net.au/news/2022-04-07/woodside-scarborough-lng-approval-despite-climate-emissions/100971214.
[147] Lewis Jackson, "Woodside's Stalled Browse LNG Project Still 'very Attractive' -CEO," Reuters, April 20, 2023, https://www.reuters.com/business/energy/woodside-energys-sales-revenue-soars-bhps-asset-addition-drives-output-2023-04-21/.
[148] Rob Nikolewski, "Sempra to Build LNG Export Facility in Baja," *The San Diego Union-Tribune*, November 17, 2020, sec. Business, https://www.sandiegouniontribune.com/business/story/2020-11-17/sempra-to-build-lng-export-facility-in-baja.
[149] Rob Nikolewski, "Sempra Planning a Second LNG Project in Mexico," *San Diego Union-Tribune*, November 5, 2021, https://www.sandiegouniontribune.com/business/story/2021-11-05/sempra-planning-a-second-lng-project-in-mexico.
[150] James Osborne, "Biden Approves Export Permits for Sempra's LNG Terminal in Mexico," *Houston Chronicle*, December 20, 2022, https://www.houstonchronicle.com/business/energy/article/DOEsempracruz-17666985.php.
[151] Nicholas Cunningham, "ConocoPhillips Agrees to Buy LNG from Mexico Pacific," *Gas Outlook*, July 8, 2023, https://gasoutlook.com/news/conocophillips-agrees-to-buy-lng-from-mexico-pacific/.

leaders as an economic driver and a means to address the nation's rising debt. By the end of 2022, lack of infrastructure—including pipelines and fracking equipment—was restraining further growth and the government began incentivizing the construction of gas pipelines.[152] In May 2023, a delegation of Argentina's Mapuche people traveled to the EU to call upon European oil and gas companies and their investors to stop fracking on Indigenous lands.[153] In June 2023, Chevron announced its intention to invest $500 million into the Vaca Muerta shale play.[154]

Southern Africa. In spite of lawsuits, investigations, and fierce local resistance, the Canadian energy company ReconAfrica licensed more than 13,000 square miles of land in the Kavango Basin of Namibia and Botswana and moved forward with its goal of drilling and fracking hundreds of wells in a region includes habitat and migratory routes for elephants and other endangered wildlife species. According to petroleum engineer Nick Steinsberger, a pioneer of fracking in Texas' Eagle Ford Shale and board member of ReconAfrica who originally led the exploratory effort in the Kavango Basin, "We're looking for the next American shale boom, and Africa's got the most potential."[155]

As of March 2023, ReconAfrica had drilled three test wells but had thus far failed to extract commercially profitable amounts of oil, raising questions about whether ReconAfrica had misled and oversold the project to investors.[156, 157] At least one of these wells is located near a riverbed in Namibia in an area that overlaps with critical habitat and migratory routes for the world's largest remaining elephant population and could affect the unique Okavango Delta.[158] The license, which includes a contracted production period of at least 25 years, also originally covered the Tsodilo Hills, a World Heritage Site with deep spiritual significance for the indigenous San people, but this area was subsequently excluded after public outcry and intervention by the United Nations Educational, Scientific, and Cultural Organization

[152] Eliana Raszewski, "Analysis: Argentina's Vaca Muerta Shale Boom Is Running out of Road," Reuters, December 27, 2022, https://www.reuters.com/business/energy/argentinas-vaca-muerta-shale-boom-is-running-out-road-2022-12-27/.
[153] Hannah Sharland, "Indigenous Mapuche Travel to Europe to Highlight Impacts of Fracking Megaproject," Canary Workers' Co-op, May 11, 2023, https://www.thecanary.co/global/world-analysis/2023/05/11/indigenous-mapuche-travel-to-europe-to-highlight-impacts-of-fracking-megaproject/.
[154] Reuters, "Argentina Says Chevron to Invest $500 Million in Vaca Muerta Shale Area," Reuters, June 9, 2023, https://www.reuters.com/business/energy/argentina-says-chevron-invest-500-mln-vaca-muerta-shale-area-2023-06-10/.
[155] James Stafford, "The World's Last Great Oilfield: An Interview with Nick Steinsberger," OilPrice.com, September 16, 2020, https://oilprice.com/Interviews/The-Worlds-Last-Great-Oilfield-An-Interview-With-Nick-Steinsberger.html.
[156] Jeffrey Barbee and Laurel Neme, "They Ripped through a Protected Wilderness to Find Oil. Instead, They Found Trouble," *National Geographic*, March 28, 2023, https://www.nationalgeographic.com/animals/article/oil-drilling-reconafrica-okavango-watershed-protected-wilderness.
[157] Timo Shihepo and Sam Sole, "Canadian Company Exploring for Oil in Namibia in Credibility Battle," *Daily Maverick*, December 15, 2022, https://www.dailymaverick.co.za/article/2022-12-15-canadian-company-exploring-for-oil-in-namibia-in-credibility-battle/.
[158] Jeffrey Barbee and Laurel Neme, "Oil Drilling, Possible Fracking Planned for Okavango Region—Elephant's Last Stronghold," *National Geographic*, October 28, 2020, https://www.nationalgeographic.com/animals/article/oil-drilling-fracking-planned-okavango-wilderness.

(UNESCO).[159, 160, 161] Fracking in this extremely arid region requires the industrialization of this pristine landscape as well as the destruction of billions of gallons of fresh water.[162, 163, 164]

In 2021, *National Geographic* reported that the waste pits created for the test wells were unlined, contrary to standard industry practice in British Columbia where the company is headquartered. Aerial photography indicated that ReconAfrica had drilled in the conservancy without first securing necessary permits, bulldozed land, and drilled a second test well inside a protected wildlife conservancy area.[165]

These continued exploration activities prompted UNESCO to express its concern about the granting of oil exploration licenses in environmentally sensitive areas within the Okavango River Basin and, as part of a formal decision, to request further regulatory oversight. Specifically, UNESCO "urges the States Parties of Botswana and Namibia to ensure that potential further steps to develop the oil project, which include the use of new exploration techniques, are subject to rigorous and critical prior review, including through Environmental Impact Assessment (EIA) that corresponds to international standards, including an assessment of social impacts and a review of potential impacts on the World Heritage property.*"*[166]

UNESCO set a deadline of February 2022 for the state parties to submit to the World Heritage Center an updated report on the state of conservation of the property and the implementation of the EIA, but this deadline and the requirement of a proper EIA was ignored by both Namibia and Botswana. Local and international groups continue to fight the project. In May 2023, international environmental organizations sent a letter to oil company CEOs warning the industry against investing in ReconAfrica's project, noting that the projected 120 billion barrels of recoverable oil in the Kavango Basin would be equivalent to one-sixth of the world's remaining carbon budget.[167]

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[159] Jeffrey Barbee and Laurel Neme, "Test Drilling for Oil and Gas Begins in Namibia's Okavango Region," *National Geographic*, January 28, 2021, https://www.nationalgeographic.com/animals/article/oil-gas-test-drilling-begins-namibia-okavango-region.
[160] Reconnaissance Energy Africa, Ltd., "Republic of Botswana and ReconAfrica Amend Exploration License to Exclude Entire Tsodilo Hills Area," Cision, January 5, 2021, https://www.newswire.ca/news-releases/republic-of-botswana-and-reconafrica-amend-exploration-license-to-exclude-entire-tsodilo-hills-area-837436712.html.
[161] UNESCO, "UNESCO Vigilant on Potential Impacts of Oil Exploration in Namibia and Botswana on World Heritage Properties," UNESCO, December 21, 2020, https://whc.unesco.org/en/news/2230.
[162] Mark Heim, "ReconAfrica Research Report," Research (ReconAfrica, July 2020), https://reconafrica.com/wp-content/uploads/ReconAfrica-Research-Report-July-2020.pdf.
[163] Jeff Goodell, "Will an Oil Racket Destroy One of Africa's Most Sacred Places?," *Rolling Stone*, March 26, 2023, https://www.rollingstone.com/politics/politics-features/oil-drilling-africa-destroy-wild-land-namibia-recon-investors-1234697088/.
[164] Lebo Diseko, "COP27: The Namibia-Botswana Oil Project Being Called a Sin," BBC.com, November 10, 2022, https://www.bbc.com/news/world-africa-63567513.
[165] Jeffrey Barbee and Laurel Neme, "Oil Company Accused of Drilling in African Wildlife Reserve, Offering Jobs for Silence," *National Geographic*, December 13, 2021, https://www.nationalgeographic.com/animals/article/oil-company-reconafrica-accused-of-drilling-in-african-wildlife-reserve.
[166] UNESCO, "Convention Concerning the Protection of the World Cultural and Natural Heritage" (United Nations, July 31, 2021), https://whc.unesco.org/archive/2021/whc-21-44com-18-en.pdf.
[167] Valentina Stackl, "Environmental NGOs Warn Oil Giants: Hands Off Okavango Delta and Kavango Basin Drilling," Oil Change International, May 30, 2023, https://priceofoil.org/2023/05/30/environmental-ngos-warn-oil-giants-hands-off-okavango-delta-and-kavango-basin-drilling/.

In June 2023, ReconAfrica paused drilling in the Okavango watershed and said it now plans to look for oil in northern Botswana. This announcement raised further questions about the company's ability to finance its activities, the accuracy of its projections regarding recoverable oil, and responsibility for the clean-up of its operations in the Okavango if its wells there are abandoned.[168]

At its September 2023 annual meetings, the UNESCO World Heritage Committee expressed deep concerns about oil and gas extraction activities in the delta and proposed expanding the Okavango World Heritage Site to include its entire watershed. This recommendation has received support from the ministries of tourism in both Angola and Botswana and, if formalized, will be voted on in 2024.[169]

Providing support for the proposal is a study published in October 2023, in which an international team of researchers calculated hydraulic gradients, flow velocity, and flow direction of groundwater and surface water in the region, concluding that current contamination from drilling sites could reach the Okavango River within a decade. Underground faulting and fractures within underground geological structures in the region may serve as even faster pathways for the flow of contaminants. The research team's calculations indicate that contamination from drilling activities that travels via these permeable geological structures—called grabens and dykes—could reach the Okavango Delta within just four days. The authors called for an immediate moratorium on all oil and gas exploration and extraction in the river basin until detailed risk assessments of water resources are undertaken.[170, 171]

[168] Jeffrey Barbee and Laurel Neme, "Canadian Oil Company Pauses Controversial Drilling in Namibian Wilderness," *National Geographic*, June 27, 2023, https://www.nationalgeographic.com/animals/article/canadian-oil-company-reconafrica-pause-drilling-namibia.
[169] Jeffrey Barbee and Laurel Neme, "Can UNESCO Safeguard This Lush African Watershed from Oil Drilling?," October 2, 2023, https://www.nationalgeographic.com/environment/article/okavango-delta-unesco-world-heritage-site-expansion.
[170] R. Sheldon et al., "Potential Groundwater Contamination from Oil Drilling in the Okavango," *Physics and Chemistry of the Earth, Parts A/B/C* 131 (October 2023): 103430, https://doi.org/10.1016/j.pce.2023.103430.
[171] Surina Esterhuyse, "Oil Drilling Threatens the Okavango River Basin, Putting Water in Namibia and Botswana at Risk," *The Conversation*, August 2, 2023, https://theconversation.com/oil-drilling-threatens-the-okavango-river-basin-putting-water-in-namibia-and-botswana-at-risk-209887.

Introduction to Fracking

How fracking works

Since the end of the 20th century, horizontal drilling has been combined with high-volume hydraulic fracturing to extract dispersed oil and natural gas, primarily from shale bedrock, that would otherwise not flow to the surface. Typically, these extraction methods (collectively known as "fracking") take place on clustered multi-well pads where individual wellbores extend vertically down into the shale formation and then turn horizontally, tunneling through the shale in various directions. These lateral tunnels can extend as far as two miles underground.

To liberate the gas (methane) or oil trapped inside the shale, many small explosive charges followed by high volumes of pressurized fluid are sent into the shale layer to expand and extend its many naturally occurring cracks, bedding planes, and faults. Silica sand grains (or sometimes ceramic beads) are carried by the pressurized fluid into these spaces and remain there after the pressure is released, acting to prop open these now-widened fissures in the shale and allowing the methane or oil trapped within to flow up the well.

Formerly called "unconventional gas and oil extraction," the techniques of fracking are now standard practice in the United States. About 40 percent of the natural gas inventory in the United States is used to generate utility-scale electricity, and, enabled by fracking, natural gas exceeded coal as the nation's leading source of electricity in 2016.[172] Hydraulically fractured wells now produce 79 percent of U.S. natural gas and 65 percent of U.S. crude oil, with hydraulic fracturing used in 95 percent of new wells.[173, 174]

Fracking fluid

Fracking fluid consists of millions of gallons of fresh water to which is added a sequence of chemicals that include biocides, lubricants, gelling agents, anti-scaling, and anti-corrosion agents. Some of the water used to frack wells remains trapped within the fractured zone and, as such, is permanently removed from the hydrologic cycle. The remainder travels back up to the surface. This flowback fluid contains not only the original chemical additives, many of which are toxic, but also harmful substances carried up from the shale zone, which often include brine, heavy metals, and radioactive elements.

[172] Bobby Magill, "Fracking Hits Milestone as Natural Gas Use Rises in U.S.," Climate Central, May 6, 2016, http://www.climatecentral.org/news/fracking-milestone-as-natural-gas-use-rises-20330.
[173] U.S. Energy Information Administration, "Natural Gas Explained: Use of Natural Gas," EIA.gov, December 7, 2021, https://www.eia.gov/energyexplained/natural-gas/use-of-natural-gas.php.
[174] U.S. Energy Information Administration, "How Much Shale Gas Is Produced in the United States?," EIA.gov, October 4, 2021, https://www.eia.gov/tools/faqs/faq.php?id=907&t=8.

Fracking waste

Once in production, a fracked well continues to generate liquid throughout its lifetime. This produced water, which contains many of the same toxic substances as flowback fluid, is a second component of fracking waste, and it also requires containment and disposal. In addition, fracking waste includes solid drilling cuttings, which are typically laced with various chemical substances used to aid the drilling process. These cuttings, which can also contain radioactive elements, are typically disposed of in municipal waste landfills. Fracking waste is exempt from federal hazardous waste regulations that would otherwise prohibit this practice.

In the United States, more than two billion gallons of water and fracking fluids are injected daily under high pressure into the earth for the purpose of enabling oil and gas extraction via fracking or, after the fracking is finished, to flush the extracted wastewater down any of the more than 187,000 disposal wells across the country that accept oil and gas waste. All of that two billion daily gallons of fluid is toxic, and the wells that ferry it pass through the nation's groundwater aquifers on their way to the deep geological strata below, where the injection of fracking waste demonstrably raises the risk of earthquakes.

Upstream and downstream elements of fracking

Downstream elements of fracking infrastructure, which lie between the wellhead and the point of combustion, include processing plants, transport infrastructure such as pipelines and compressor stations, distribution lines, storage facilities, gas-fired power plants, and LNG liquefaction plants and export terminals. Upstream elements include silica sand mining operations and water withdrawal operations.

Legal secrecies

Industry secrecy continues to thwart scientific inquiry into the health and environmental impacts of fracking's many component parts and operations, leaving many potential problems—especially cumulative, long-term risks—unidentified, unmonitored, and largely unexplored. This problem is compounded by non-disclosure agreements, sealed court records, and legal settlements that prevent families and their doctors from discussing injuries and illnesses that result from fracking and related operations.

The long-entrenched problem of secrecy shows no sign of resolving. The identity of chemicals used in fracking fluids remains proprietary and lies beyond the reach of federal right-to-know legislation that governs other industries. The nation's largest public database on chemicals used in fracking operations, FracFocus, operates on a voluntary basis, and while 23 states have adopted it to serve as a *de facto* chemical disclosure registry, its data has, over time, become increasingly less, rather than more, comprehensive and transparent. Rates of withheld information and claims of trade secrecy increased during the five-year period after FracFocus was launched in 2011. (See footnotes 2517 and 2518.)

The incomplete picture created by a lack of transparency in regard to chemicals used, produced, emitted, or created during the drilling and fracking process complicates the task of identifying potential hazards and exposure pathways. Nevertheless, the evidence to date indicates that fracking operations pose severe threats to health, both from water contamination and from air pollution.

In the air around drilling and fracking operations and their attendant infrastructure, researchers have measured strikingly high levels of toxic pollutants, including the potent carcinogen benzene and the chemical precursors of ground-level ozone (smog). In some cases, concentrations of fracking-related air pollutants in communities where people live and work exceed federal safety standards. Research shows that air emissions from fracking can drift and pollute the air hundreds of miles downwind. (See footnotes 576, 577.)

The geography of fracking

Drilling and fracking operations and their ancillary infrastructure have profoundly altered Earth's landscape. The flare stacks and artificial lights from major shale plays are visible from space,[175] as is the upward buckling of Earth's surface that is caused by the high-pressure injection of fracking wastewater into disposal wells.[176]

The dramatic increase in fracking over the last decade in the United States has pushed oil and gas extraction operations into heavily populated areas. In the Marcellus Shale alone, which underlies much of the Mid-Atlantic United States, 15,939 wells were drilled and fracked between 2008 and 2018.[177] More than 11,000 of these wells are in Pennsylvania.

At least six percent of the U.S. population—17.6 million Americans—live within a mile of an active oil or gas well, a number that includes 1.4 million young children and 1.1 million elderly people.[178, 179] About 8.6 million people are served by a drinking water source that is located within a mile from an unconventional well. (See footnote 755.) Understanding the potential for exposure and accompanying adverse impacts is a public health necessity.

[175] "Shale Revolution: As Clear as Night and Day," NASA Earth Observatory, February 15, 2016, http://earthobservatory.nasa.gov/IOTD/view.php?id=87725&src=eoa-iotd.
Andy Coghlan, "You Can See Fracking's Impact on Earth's Surface from Space," NewScientist, September 22, 2016, https://www.newscientist.com/article/2106886-you-can-see-frackings-impact-on-earths-surface-from-space/.
[177] Jeffrey B. Jacquet et al., "A Decade of Marcellus Shale: Impacts to People, Policy, and Culture from 2008 to 2018 in the Greater Mid-Atlantic Region of the United States," *Extractive Industries and Society* 5, no. 4 (2018): 596–609, https://doi.org/10.1016/j.exis.2018.06.006.
[178] Eliza D. Czolowski et al., "Toward Consistent Methodology to Quantify Populations in Proximity to Oil and Gas Development: A National Spatial Analysis and Review," *Environmental Health Perspectives* 125, no. 8 (2017), https://doi.org/10.1289/EHP1535.
[179] Lindsey Konkel, "In the Neighborhood of 18 Million: Estimating How Many People Live near Oil and Gas Wells," *Environmental Health Perspectives* 125, no. 12 (2017), https://doi.org/10.1289/EHP2553.

Timeline of Fracking Bans and Moratoria

As a response to the proliferating documentation of the risks and harms of fracking—augmented by increasing evidence of its declining benefits and unrealized promises—various countries, states, and municipalities have instituted bans and moratoriums.[180]

France banned fracking in July 2011. In 2017 this ban was extended to include all exploration and extraction of oil and gas within France and all its territories until 2040.

The government of **North Ireland** declared a moratorium on fracking in December 2011. In February 2022, Northern Ireland's Minister for the Economy Gordon Lyons announced that the preferred option resulting from his Department's policy review would be a ban on all forms of petroleum licensing.

Bulgaria banned fracking in January 2012.

In May 2012, the state of **Vermont** banned fracking and prohibited the storage and treatment of fracking waste.

In July 2012, a revision of environmental laws in **Austria** prompted the main Austrian oil and gas group to announce a stop to its shale gas plans in the country.

In April 2013, the **Luxembourg** parliament passed a motion against shale gas exploration.

In October 2013, after extended anti-fracking protests, U.S.-based Chevron pulled out of **Lithuania**, blaming regulatory and legislative restrictions that came into place after it had won permits for shale gas exploration. There is currently no fracking in Lithuania.[181]

In July 2014, the Flanders region of **Belgium** temporarily banned fracking. This ban is still valid. There is currently no domestic gas extraction in Belgium.

The **California** counties of Santa Cruz, San Benito, and Mendocino all banned fracking in 2014.

New York State banned fracking in December 2014.

In January 2015, **Scotland** became the first country in the United Kingdom to impose a formal moratorium on fracking. In 2016, as part of the ongoing moratorium process, the government of Scotland released a series of reports that reconfirmed the evidence for potential contamination of air and water, threats to worker health from silica dust exposure, and risks to the health of nearby residents. It further noted that the pursuit of unconventional oil and gas extraction would make it

[180] Héctor Herrera, "The Legal Status of Fracking Worldwide: An Environmental Law and Human Rights Perspective," The Global Network for Human Rights and the Environment, January 6, 2020, https://gnhre.org/2020/01/06/the-legal-status-of-fracking-worldwide-an-environmental-law-and-human-rights-perspective/.
[181] Andreea Maierean, "What Went Wrong? Fracking in Eastern Europe," *Discover Energy* 1, no. 1 (August 16, 2021): 3, https://doi.org/10.1007/s43937-021-00003-5.

more difficult for Scotland to achieve its climate targets on greenhouse gas emissions.[182, 183] In October 2017, Scotland's moratorium was extended "indefinitely" in a decision that led to an unsuccessful court challenge by the British petrochemical company Ineos. In 2019, the government confirmed that would no longer issue licenses for fracking nor grant permission for any onshore drilling projects.[184] In 2020, Ineos purchased tens of thousands of acres of leases near Austin, Texas and applied for fracking permits.[185]

In February 2015 the government of **Wales** declared a moratorium on fracking "until it is proven safe." In July 2018, the Welsh government confirmed that shale gas was not compatible with decarbonization targets and said it would not support applications for fracking.

In March 2015, the Canadian province of **New Brunswick** declared a moratorium on fracking and in 2016 extended it indefinitely, citing unresolved problems with the disposal of fracking wastewater. In 2019, the moratorium was lifted in the Sussex area where a small gas industry had been operating prior to the moratorium and was seeking to attract investors. However, the obligation to consult with Indigenous peoples remained in effect and no proponent came forward with a proposal.[186] In March 2023, Premiere Blaine Higgs reignited the attempt to lift the moratorium in the Sussex area in a letter to First Nations' chiefs that emphasized fracking's revenue potential.[187]

In July 2015, the **Netherlands** banned all shale gas fracking through 2020 and then extended the ban to 2023. n October 2018, the Dutch government announced that gas extraction of all kinds in the Groningen gas field would entirely cease by 2030 after public outcry over continuing earthquakes in the region. Gas production has already been cut by 60 percent since its peak in 2013. On May 22, 2019, Groningen was hit with a magnitude 3.4 earthquake that damaged multiple homes.[188]

In August 2015, **Denmark** declared a stop to new applications for shale gas drilling, extending its 2012 moratorium.

In December 2015, the plenary of the **European Parliament** affirmed the incompatibility of shale gas extraction via hydraulic fracturing with the European Union's commitment to

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[182] Health Protection Scotland, "A Health Impact Assessment of Unconventional Oil and Gas in Scotland: Volume 1 - Full Report" (Public Health Scotland, November 8, 2016), http://www.hps.scot.nhs.uk/resourcedocument.aspx?resourceid=3102.

[183] Energy and Climate Change Directorate, "Unconventional Oil and Gas: Compatibility with Scottish Greenhouse Gas Emissions Targets," Research and Analysis, Scottish Government, November 8, 2016, http://www.gov.scot/Resource/0050/00509324.pdf.

[184] Severin Carrell, "Scottish Government Extends Ban on Fracking," October 19, 2019, sec. UK Politics, https://www.theguardian.com/uk-news/2019/oct/03/scottish-government-extends-ban-on-fracking.

[185] Sergio Chapa, "Drilling down: British Petrochemical Giant Ineos Plans to Begin Fracking in Texas," *Houston Chronicle*, May 7, 2020, sec. Sector News, https://www.borderless.net/news/chemical-value-chain/drilling-down-british-petrochemical-giant-ineos-plans-to-begin-fracking-in-texas/.

[186] Silas Brown, "New Brunswick Indigenous Chiefs Left 'blindsided' by Decision to Lift Fracking Moratorium," *Global News*, June 5, 2019, https://globalnews.ca/news/5356115/indigenous-chiefs-issue-warning-gas-fracking/.

[187] Aidan Cox, "Higgs Pitches First Nations on up to $1.6B in Revenue with Possible Shale Gas Expansion," *CBC News*, March 30, 2023, https://www.cbc.ca/news/canada/new-brunswick/new-brunswick-fracking-shale-gas-first-nations-1.6794489.

[188] "Groningen Hit by Strong Earthquake as Gas Extraction Impact Continues," *Dutch News*, May 22, 2019, https://www.dutchnews.nl/news/2019/05/groningen-hit-by-strong-earthquake-as-gas-extraction-impact-continues/.

decarbonization, and it acknowledged public concerns about the environmental and health impacts of fracking. While falling short of an outright EU-wide moratorium on fracking, the report states that "it is questionable whether hydraulic fracturing can be a viable technology in the European Union."[189]

In January 2016, **Broward County, Florida**, one of three counties that make up the larger Miami metropolitan region, banned both hydraulic fracking and acid fracking via a unanimous vote of the Broward County Commission.

In 2016 a government-appointed panel in the Canadian province of **Newfoundland and Labrador**, where a moratorium had been in place since 2013, recommended that fracking remain "paused," citing data gaps and unresolved questions about the underlying geology.

In June 2016, **Germany** adopted a moratorium on fracking in shale but allowed exploratory drilling research projects. This moratorium, which was due to be reviewed in 2021, remains in place. Fracking in sandstone is explicitly permitted.

Also in 2016, Butte and Alameda counties in **California** banned fracking, along with Monterey County, which also banned all new oil drilling.

In August 2016, the state of Victoria in **Australia** halted both fracking and conventional gas extraction on the grounds that the risks outweighed any potential benefits. In March 2020, the fracking ban became permanent while the ban on conventional drilling without fracking was lifted.[190]

In September 2016, a **California** judge, arguing that the agency had failed to consider the dangers of fracking, struck down a bid by the Bureau of Land Management (BLM) to open one million acres of public land in central California to oil drilling.

In November 2016, Winona County, **Minnesota** banned the mining of frack sand, a decision that was upheld in district court in November 2017 and upheld again by the Minnesota Supreme Court in March 2020.[191, 192] In January 2021 the U.S. Supreme Court refused to hear the case, and the Winona County ban on frack sand mining prevailed.[193]

In December 2016, the Portland City Council in **Oregon** approved zoning code changes that banned the construction of new fossil fuel projects, including terminals for storing and

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[189] Committee on Industry, Research and Energy, "Report: On towards a European Energy Union" (European Parliament, n.d.), http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//TEXT+REPORT+A8-2015-0341+0+DOC+XML+V0//EN.
[190] Samantha Hepburn, "Victoria Bans Fracking for Good, but Quietly Lifts Onshore Gas Exploration Ban," Phys.org, March 19, 2020, https://phys.org/news/2020-03-victoria-fracking-good-quietly-onshore.html.
[191] Chris Rogers, "Supreme Court Considers Frac Ban," *Winona Post*, April 17, 2019, http://www.winonapost.com/Article/ArticleID/63818/Supreme-Court-considers-frac-ban.
[192] Matt McKinney, "Minnesota Supreme Court Upholds Winona County Ban on Frac Sand Mining," *StarTribune*, March 11, 2020, https://www.startribune.com/minnesota-supreme-court-upholds-winona-county-ban-on-frac-sand-mining/568701922/.
[193] Matt McKinney, "U.S. Supreme Court Rejects Suit against Winona County Frac Sand Ban," *Star Tribune*, January 12, 2021, https://www.startribune.com/u-s-supreme-court-rejects-suit-against-winona-county-frac-sand-ban/600009755/.

transporting natural gas, and also prohibited the expansion of pre-existing facilities, including an LNG plant.

In 2017, Ponca Nation in northern **Oklahoma** banned fracking on Ponca lands by passing a Rights of Nature law declaring that natural elements possess inalienable rights.[194]

In March 2017, the Castilla Leon region in **Spain** signed a political agreement to give up on shale gas exploration. This decision followed the implementation of several other regional bans in Spain or laws that otherwise made fracking unviable. These regions include Cantabria (April 2013), La Rioja (May 2013), Catalonia (February 2014), Basque Country (June 2015), and Castillo La Mancha (March 2017). In May 2021, Spain passed a climate bill that banned fracking nationwide and banned all new oil and gas exploration.

In April 2017, **Maryland** became the third U.S. state to ban fracking when Governor Larry Hogan signed a ban bill that was overwhelmingly approved by the state legislature. Maryland's ban followed a two-and-a-half-year statewide moratorium.

Also in April 2017, Entre Ríos passed the first province-wide ban on fracking in **Argentina**. This ban follows 50 individual municipal bans and is intended to protect the Guarani Aquifer, which extends beneath parts of Argentina, Brazil, Paraguay, and Uruguay.

In June 2017, **France** expanded its fracking ban to include a ban on all new oil and gas exploration.

In July 2017, **Ireland** banned fracking when legislation was signed into law by the president.

Also in October 2017, Canada's **Prince Edward Island** included a prohibition on fracking as part of its Water Act.

In December 2017, **Uruguay** prohibited fracking for four years.

In March 2018, the **Australian state of Tasmania** extended its moratorium on fracking until 2025.

In October 2018, the National Authority for Environmental Licenses denied applications for commercial fracking in **Colombia.** In December 2019, the Colombian Ministry of Mines approved a regulatory framework for fracking pilot studies. In April 2022, a judge suspended the license of one such project on the grounds that Afro-Colombian communities had not been consulted.

In December 2018, the newly elected president of **Mexico** announced a suspension of all further energy auctions for three years, temporarily halting permits for new fracking operations. This announcement was widely seen as a possible step by President Obrador toward fulfilling a campaign promise to ban fracking in Mexico.[195] However, he has not done so. In January 2023,

[194] Ray Levy Uyeda, "Indigenous Activists Look to Rights of Nature Laws to Stop Fracking," Daily Kos, October 28, 2022, https://www.dailykos.com/stories/2022/10/28/2130922/-Indigenous-activists-look-to-Rights-of-Nature-laws-to-stop-fracking.
[195] Rebecca Bertram, "Will Fracking Be Banned in Mexico?," Energy Transition, April 17, 2019, https://energytransition.org/2019/04/will-fracking-be-banned-in-mexico/.

Mexico's Safety, Energy and Environment Agency began preparing a rule for both its state-owned oil company (Pemex) and private companies to frack for oil and gas after the next president takes office in December 2024. Pemex has already drilled and fracking at least three wells.[196]

In May 2019, **Washington State** enacted a statewide ban on fracking.

In June 2019, the state of **Oregon** put in place a five-year fracking moratorium.

Also in June 2019, the state of **Connecticut**, where no fracking takes place, banned the disposal of oil and gas extraction waste.

In November 2019, **the United Kingdom** declared a moratorium on fracking after an Oil and Gas Authority analysis found that preventing earthquakes associated with fracking is not possible with existing technology but left open the possibility that the temporary ban could be reversed if induced seismicity became manageable. In April 2022, the government ordered a new report from the British Geological Survey to assess any recent changes to the science, a decision seen by the industry as a possible first step toward overturning the ban.[197]

Also in November 2019, Governor Gavin Newsom announced a moratorium on all new fracking and cyclic steam permits for the state of **California**. This moratorium lasted until April 2020 when 24 new permits were issued for fracking in Kern County.[198]

In April 2020, the state legislature, in a bill signed by Governor Ralph Northam, banned fracking east of I-95 in the state of **Virginia**.

On August 3, 2020, **New York State** banned the importation of out-of-state fracking waste for disposal in municipal waste landfills and wastewater treatment plants. Seven different landfills across New York State had accepted liquid and solid fracking waste from Pennsylvania.

In February 2021, the Delaware River Basin Commission—which consists of governors of New York, New Jersey, Pennsylvania, and Delaware together with the U.S. Army Corps of Engineers—finalized a rule to permanently ban fracking in the **Delaware River watershed** on the grounds that fracking exposes its waters to "significant, immediate, and long-term risks." This ban replaces a temporary moratorium on fracking that had been in place since 2010.[199] In October 2021, the Commission proposed additional rules that would prohibit the discharge of fracking wastewater to water or land within the Basin but that would not explicitly disallow the

[196] Arturo Solís, "Exclusive: Mexico Prepares Environmental Framework for Future Fracking," *Bloomberg Línea*, January 3, 2023, https://www.bloomberglinea.com/english/exclusive-mexico-prepares-environmental-framework-for-future-fracking/.
[197] "Business Secretary Kwasi Kwarteng Orders Scientific Review of Fracking Impact," BBC.com, April 5, 2022, https://www.bbc.com/news/uk-politics-60999026.
[198] Janet Wilson, "Fracking in California Gets Green Light after 9-Month Pause; Aera Energy Receives Permits," *Desert Sun*, April 3, 2020, https://www.desertsun.com/story/news/environment/2020/04/03/calgem-approves-24-fracking-permits-aera-energy-after-9-month-pause/2944712001/.
[199] Michael Rubinkam, "Agency Permanently Bans Fracking Near Delaware River," PBS.org, February 25, 2021, https://www.pbs.org/newshour/nation/agency-permanently-bans-fracking-near-delaware-river.

importation of wastewater from fracking operations located outside the Basin.[200] In spring 2023, the Commission clarified its policy language to remove this loophole after a citizen group filed federal lawsuit.[201, 202] The longest free-flowing river in the Northeast, the Delaware River provides drinking water to more than 15 million people (approximately five percent of the U.S. population). About one-third of the river's watershed is underlain by the Marcellus shale formations.

In 2021 and 2022 prohibitions under multiple jurisdictions advanced in **California.** In April 2021, Governor Gavin Newsom announced a plan to ban fracking of new and existing wells by 2024 and to consider phasing out oil production statewide by 2045. In practice, the state has begun denying fracking permits, citing climate concerns.[203] In September 2021, the Los Angeles County Board of Supervisors voted unanimously to end oil and gas drilling in the County's "unincorporated" areas, which includes 1,600 wells, many in the Inglewood Oil Field, one of the largest urban drilling sites in the country. Effective November 2021, Culver City, California prohibited the drilling of any new, or redrilling of any existing, gas or oil well. The City Council also required the phasing out, plugging and restoration of all existing gas and oil wells, by November 24, 2026. A portion of the Inglewood Oil Field, one of the largest U.S. urban oil fields, lies within Culver City. In January 2022, the Los Angeles City Council voted unanimously to ban new oil and gas wells and phase out existing ones. [See also Case Study: Drilling and Fracking in California, p. 98.]

In April 2022, in a unanimous vote by the National Assembly, **Slovenia** imposed a complete ban on fracking in the face of threatened lawsuits by a UK-based fracking investor seeking to extract gas in the northeastern part of the country.[204]

In April 2023, a fracking ban in **Colombia** passed the Senate and is expected to win congressional approval. The ban is part of a larger policy initiative by the Colombian state to transition to renewable energy within two years.[205, 206]

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[200] Delaware River Basin Commission, "Full Text of FAQ: Proposed Regulations Addressing Importation and Exportation of Water and the Discharge of Wastewater from High Volume Hydraulic Fracturing," December 7, 2021, https://www.state.nj.us/drbc/meetings/proposed/notice_import-export-rules_faq_full-text.html.
[201] Michael Rubinkam, "Agency Clarifies Frack Waste Ban in Delaware River Watershed," *AP News*, April 28, 2023, https://apnews.com/article/delaware-river-fracking-wastewater-ban-a23a62bb7187665f2f2bfcb32845dd9f.
[202] Delaware River Basin Commission, "Full Text of FAQ (Revised): Final Regulations Addressing Importation and Exportation of Water and the Discharge of Wastewater from HVHF and HVHF-Related Activities," Delaware River Basin Commission, March 28, 2023, https://www.nj.gov/drbc/about/regulations/finalrule_import-export-hvhf-discharge_FAQtext_revised.html.
[203] Los Angeles Times Editorial Board, "Did California Issue Its Last Fracking Permit? Let's Hope So," *Los Angeles Times*, December 17, 2021, https://www.latimes.com/opinion/story/2021-12-17/fracking-permits.
[204] Sebastijan R. Maček, "Slovenia Imposes Blanket Ban on Fracking," isds.bilaterals.org, April 7, 2022, https://www.isds.bilaterals.org/?slovenia-imposes-blanket-ban-on.
[205] Luis Jaime Acosta, Griffin, and Sabrina Valle, "Exclusive: As Colombia Moves to Ban Fracking, Exxon Seeks to Recover Investment," Reuters, April 27, 2023, https://www.reuters.com/world/americas/colombia-moves-ban-fracking-exxon-seeks-recover-investment-sources-2023-04-27/.
[206] Patricia Rodríguez, "Is Colombia One Step Away from a Fracking Ban?," *NACLA*, February 8, 2023, https://nacla.org/colombia-one-step-away-fracking-ban.

In May 2023, Croatia banned large-scale fracking operations although exploratory activities are still allowed.[207]

In sum, as evidence continues to mount of its environmental and public health costs, legislative and governmental bodies are increasingly apprehensive about the risks and harms of fracking.

Nevertheless, in several notable cases, hard-won bans and other restrictions on fracking have been overturned:

A fracking ban passed by the city of **Denton, Texas** in 2014 was invalidated in 2015 by a state law, pushed by oil and gas interests, that prohibits Texas municipalities from passing local bans.

In **Colorado,** the Colorado Supreme Court struck down local fracking bans in the cities of Fort Collins and Longmont in May 2016, and a subsequent attempt to reinstate the ban in Longmont was struck down by a Boulder district judge in November 2020. In January 2019, the Colorado Supreme Court ruled against a case brought by six youth that would have halted new drilling permits pending a comprehensive study of health and environmental impacts. The ruling allows Colorado to continue to weigh costs and technical feasibility against adverse public health impacts. A statewide ballot measure (Proposition 112) to increase well setback distances to 2,500 feet from occupied buildings, public spaces, and bodies of water narrowly failed in November 2018. According to the Colorado Oil and Gas Conservation Commission, the measure would have prevented drilling on approximately 85 percent of non-federal lands in the state.

In April 2019, the Colorado State legislature passed a bill (SB 181) intended to reorient state oversight of the oil and gas industry away from promoting fossil fuel extraction and toward protecting public health and the environment. As a result of the law, the state setback distance was set at 2,000 feet. This buffer zone applies only to new wells on new well pads and allows for the drilling and fracking of new wells on pre-existing well pads. Further, the rule allows requests for waivers. In March 2022, the Colorado Oil and Gas Conservation Commission (COGCC) denied a waiver request from Occidental Petroleum for a large proposed fracking site that would have drilled 26 wells fewer than 2,000 feet from 62 homes in a residential area of Firestone.[208] SB 181 also grants Colorado municipalities more regulatory authority over fracking activities. In February 2022, the Broomfield city council banned the use of perfluoroalkyl and polyfluoroalkyl substances (PFAS chemicals) in fracking operations.[209] Nevertheless, waivers were granted for three different projects sited closer than 2,000 feet from homes in 2021 and at least one, thus far, in 2022. A 2022 analysis of the impact of SB 181 in Colorado one year after its implementation found that the reforms wrought by this legislation have, up to now, led to many changes in process but few in outcome. "The oil and gas industry still largely gets its way with the agency and residents near oil and gas facilities are still suffering from negative effects to their health, safety, and welfare. The COGCC still operates from an outlook that presumes permitting of new

[207] Total Croatia News, "Parliament Amends Law to Ban Large-Scale Hydraulic Fracturing," *Total Croatia*, May 11, 2023, https://total-croatia-news.com/news/politics/parliament-amends-law-to-ban-large-scale-hydraulic-fracturing/.
[208] Judith Kohler, "Colorado Regulators Reject Drilling Plan near Homes in Growing Firestone Community," *Greeley Tribune*, March 10, 2022, https://www.greeleytribune.com/2022/03/10/colorado-rejects-kerr-mcgee-firestone-drilling-plan/.
[209] Sydney McDonald, "PFAS Chemicals Banned in Broomfield Fracking Operations," *Daily Camera*, February 9, 2022, https://www.dailycamera.com/2022/02/09/pfas-chemicals-banned-in-broomfield-fracking-operations/.

facilities and the continued operation of existing facilities rather than first determining whether those activities are truly protective of people, the environment, and wildlife."[210]

In December 2017, **Australia's Northern Territory** government delayed a decision to extend or lift a fracking moratorium after a draft final report identified multiple risks to water, land, tourism, and indigenous culture. In April 2018, it lifted this moratorium. In September 2021, more than 60 climate scientists issued a dire warning over the plan to frack in the **Beetaloo Basin** within the Northern Territory after the federal government used grants to incentivize gas exploration there.[211, 212] In October 2021, Empire Energy won approval to begin fracking in the Beetaloo Basin. In December 2021, a territorial court voided the fracking grants but did not rule against fracking. Consultation with traditional landowners was the subject of a Senate inquiry in March 2022.[213] In May 2023, the Northern Territory government said that it was satisfied with the inquiry, clearing the way for fracking to begin.[214] In September 2023, a report by health professional based on more than 300 peer-reviewed studies documented threats from fracking in the Beetaloo to climate, biodiversity, water, food, air, soil, and "physical, social, emotional, and spiritual health."[215]

In November 2018, the statewide moratorium in **Western Australia** was lifted over intense opposition, highlighting the limitations of aboriginal land rights. Local bans in heavily populated areas of the state were left in place.

In August 2023, the California Supreme Court ruled against a ballot initiative (Measure Z) that, seven years earlier, had banned fracking, banned new oil and gas wells, and phased out wastewater disposal in **Monterey County, California.**[216]

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[210] Mike Foote and Casey Morris, "COGCC: One Year After Mission Change," Prepared for Colorado Sierra Club, January 17, 2022, https://www.larimerallianceblog.org/wp-content/uploads/2022/01/COGCC-One-Year-After-Mission-Change-1.pdf.
[211] "Over 60 Scientists & Experts Call on NT Chief Minister Gunner to Honour Commitment to Net-Zero Fracking Emissions," The Australia Institute, September 23, 2021, https://australiainstitute.org.au/post/over-60-scientists-experts-call-on-chief-minister-gunner-to-honour-commitment-to-net-zero-fracking-emissions/.
[212] Christopher Knaus, "'Grave Mistake': Climate Scientists Issue Dire Warning over Beetaloo Basin Fracking Plans," *The Guardian*, September 22, 2021, https://www.theguardian.com/australia-news/2021/sep/23/grave-mistake-climate-scientists-issue-dire-warning-over-beetaloo-basin-fracking-plans.
[213] Christopher Knaus, "Beetaloo Traditional Owners yet to Be Consulted on Production of Fracking Gas, Senate Inquiry Hears," *The Guardian*, March 21, 2022, https://www.theguardian.com/australia-news/2022/mar/22/beetaloo-traditional-owners-yet-to-be-consulted-on-production-of-fracking-gas-senate-inquiry-hears.
[214] Lisa Cox, "Northern Territory Clears Way for Fracking to Begin in Beetaloo Basin," *The Guardian*, May 2, 2023, https://www.theguardian.com/australia-news/2023/may/03/northern-territory-clears-way-for-fracking-to-begin-in-beetaloo-basin.
[215] Melissa Haswell, Jacob Hegedus, and David Shearman, "The Risks of Oil and Gas Development for Human Health and Wellbeing: A Synthesis of Evidence and Implications for Australia" (Office of the Deputy Vice Chancellor (Indigenous Strategy and Services), University of Sydney., 2023), https://apo.org.au/node/324169.
[216] Sophie Austin, "California High Court Says County Can't Enforce Oil Well Ban as State Debates Future of Fossil Fuels," *Associated Press*, August 3, 2023, https://apnews.com/article/california-oil-gas-wells-vote-ballot-2024-40519fda5272d7d8d0fdaba94ea74ad7.

Timeline of Medical Calls for Fracking Bans and Moratoria

Health professionals are increasingly calling for bans or moratoriums on fracking, based on a range of health hazards and as reviews of the data confirm evidence for harm. Concerned Health Professionals of New York, which provided scientific and medical guidance for the successful effort to ban fracking in New York State, helped launch a movement by health professionals that has grown both nationally and, increasingly, around the world. It has inspired multiple affiliations of like-minded public health scientists and health care providers that have been advocating for moratoriums or bans on fracking, including Concerned Health Professionals of Maryland, Concerned Health Professionals of Pennsylvania, Concerned Health Professionals of Ireland, Concerned Health Professionals of Neuquén, Argentina, and Concerned Health Professionals UK.

In May 2015, the **Medical Society of the State of New York** passed a resolution recognizing the potential health impacts of natural gas infrastructure and pledging support for a governmental assessment of the health and environmental risks associated with natural gas pipelines. (See footnote 2053.) The American Medical Association (AMA) adopted a similar resolution that supports legislation requiring all levels of government to seek a comprehensive Health Impact Assessment regarding the health and environmental risks associated with natural gas pipelines. (See footnote 2052.)

In May 2016, **Physicians for Social Responsibility** called for a ban on fracking. (See footnote 2515.)

In July 2016, the UK health professional organization **Medact** released an updated assessment of the potential health impacts of shale fracking in England, concluding that the United Kingdom should abandon its policy to encourage shale gas extraction and urged an "indefinite moratorium" on fracking. (See footnote 2513.)

In October 2016, a group of **health care professionals in Massachusetts** called for an immediate moratorium on major new natural gas infrastructure until the impact of these projects on the health of the communities affected could be adequately determined through a comprehensive Health Impact Assessment. (See footnotes 2509, 2510.) The group noted that the operation of natural gas facilities increases the risk of human exposures to toxic, cancer-causing, and radioactive pollution due to the presence of naturally co-occurring contaminants, toxic additives to the hydraulic fracturing process, and through the operation of transmission pipelines.

Also in 2016, in a unanimous vote of the society's 300-member House of Delegates, the **Pennsylvania Medical Society** called for a moratorium on new shale gas drilling and fracking in Pennsylvania and an initiation of a health registry in communities with pre-existing operations. (See footnotes 2507, 2508.)

In March 2019, **Doctors for the Environment Australia** announced the reinforcement of its position that no new gas extraction of any kind should occur in Australia. (See footnote 2482.)

In November 2019, **over 100 leading Israeli scientists**, including Nobel laureate Robert

Aumann, called for the reversal of the government's decision to build a new network of gas-fired power plants and appealed for a transition to renewable energy. "During the production, refining and delivery of the gas, much greater quantities of methane are released than were previously recognized. These emissions contain volatile organic compounds that are recognized as carcinogenic." (See footnote2478.)

In January 2020, the **Canadian Association of Physicians for the Environment** called for a moratorium on the development of new fracked natural gas wells in each province and territory across Canada and a plan to phase out existing fracking wells to meet Canada's commitments under the Paris Agreement. In addition, they asked for health assessments to prioritize wells for early closure and just transition for industry workers to help them prepare for a new low-carbon economy. (See footnote 2475.)

In December 2020, **the Massachusetts Medical Society** passed a resolution calling for "a legislative review of the approval process of the Enbridge natural gas compressor station in Weymouth and why the health impact assessment did not include a safety evacuation plan, an assessment of the project's climate impact, or consideration of the important health risks from emissions to the children who live in close proximity to the compressor."

In February 2022, **United Kingdom medical institutions** called for an immediate halt to new oil and gas exploration. "As healthcare professionals, we know that any new fossil fuel projects and their contribution to climate change constitute a grave threat to our patients and the resilience of our healthcare system." (See footnote 2464.)

In December 2022, a group of physicians in **British Columbia** called for a moratorium on fracking in the province, after their survey of 53 respondents who lived within five kilometers of oil and gas operations described their extensive list of acute and chronic physical and mental health conditions. The doctors also cited the scientific research on health harms. (See footnote 2462.)

In June 2023, 45 pediatricians in Australia's Northern Territory (NT) signed a joint letter sign joint letter urging NT government to withdraw their support for fracking in the **Beetaloo Basin.** The demand sought to avoid the health harms documented in populations living in proximity to fracking in the United States. (See footnote 2460.)

In August 2023, an alliance of 27 health leaders in the United Kingdom called on prime minister Rishi Sunak to withdraw licenses for oil and gas extraction in the **North Sea** and commit to a renewable energy transition out of deep concern "about the impact that climate change and nature loss are having on human health."[217]

[217] Richard Smith, "New Licenses for Oil and Gas Drilling Will Exacerbate Climate Crisis—an Open Letter to the PM," *BMJ*, August 2, 2023, p1794, https://doi.org/10.1136/bmj.p1794.

Major Trends

1) Regulations are incapable of preventing harm.

Studies reveal inherent problems in the natural gas and oil extraction process, such as well integrity failures caused by aging or the pressures of fracking itself, in the process of extracting fracking fluids from the well, and in the waste disposal process. These issues lead to water contamination, greenhouse gas emissions, air pollution with carcinogens and other toxic chemicals, earthquakes, and a range of health, environmental and other stressors inflicted on communities.

Some of fracking's many component parts—which include the subterranean geological landscape itself—are simply not controllable.

Compounding the innate unpredictability of the fracking process: The number of wells and their attendant infrastructure continues to proliferate, creating burgeoning cumulative impacts, and the size of individual wells keeps growing. With the horizontal portions of a single well now extending as far as two miles or more underground, fluid injections, once typically three to five million gallons per fracked well, now can easily reach 10 to 20 million gallons per well.

The injection of ever-increasing volumes of fluids into an ever-increasing number of wells creates significant deformations in the shale. These are translated upwards, a mile or more, to the surface. Along the way, these "pressure bulbs" can impact, in unpredictable ways, faults and fissures in the overlying rock strata, including strata that intersect freshwater aquifers. Such pressure bulbs may mobilize contaminants left over from previous drilling and mining activities. (See footnotes 823, 824.) No set of regulations can obviate these potential impacts to groundwater.

Regulations cannot eliminate earthquake risks. (See footnote 1384.) Fracking activities have triggered earthquakes around the world. In spite of emerging knowledge about the mechanics of how fracking and the underground disposal of fracking waste trigger earthquakes via activation of faults, no model can predict where or when earthquakes will occur or how powerful they will be. Induced earthquakes can occur many miles from fracking sites. (See footnote 280.) According to the UK's Oil and Gas Authority, methods for predicting a relationship between the volume of injected fracking fluids and the location, timing, and magnitude of seismic activity "lack convincing empirical evidence or proven theoretical basis." (See footnote 1317.)

Regulations cannot prevent air pollution. The state of California determined that fracking could have "significant and unavoidable" impacts on air quality, including driving pollutants to levels that violate air quality standards. (See footnote 566.) In northeastern Colorado, ambient levels of atmospheric hydrocarbons have continued to increase even with stricter emission standards. (See footnote 581.) Tighter state regulations and tougher enforcement, including unannounced visits by state health inspectors equipped with infrared cameras, have reduced leaking methane and toxic vapors at individual well sites, but total air emissions continue to rise as the total number of wells continues to increase. There are more than 53,000 active oil and gas wells in Colorado.

Regulations cannot stop radioactive emissions. Radioactive elements commonly found in shale formations are released during the process of drilling and fracking. They may accumulate in tubes, pipes, and equipment at fracking sites at levels known to cause health risks. Excess radioactivity has been detected in the soil near well pads, downstream of water facilities where fracking wastewater is treated, and in municipal landfills where fracking waste is dumped. (See footnotes 971, 973.) Radioactive liquids and solid drilling waste from fracking operations in the United States are essentially unregulated. Radioactive airborne particles are also released from fracking wells themselves and are detectable in residential areas downwind from drilling and fracking operations.[218]

Regulations cannot stop wells from leaking. Methane leakage of active wells is wildly variable: Four percent of wells nationwide are responsible for fully half of all methane emissions from drilling and fracking-related activities. Predicting which wells will become "super-emitters" is not possible, according to a survey of 8,000 wells using helicopters and infrared cameras. However, marginal wells near the end of their lifespans—so-called stripper wells—appear to represent a disproportionately large source of methane emissions relative to their production, sometimes leaking more gas than is extracted and put into a pipeline.[219] Stripper wells are typically not profitable to operate but, because the cost of decommissioning them can be greater than the cost of keeping them running, they remain online or at the ready.

In addition to unintentional well leakage, purposeful methane releases are engineered into the routine operation of fracking extraction, processing, and transport infrastructure, as when vapors are vented through release valves in order to regulate pressure and prevent explosions. These releases are not fixable plumbing problems. (See footnotes 1808, 1809.)

2) Idle, abandoned, and orphaned wells contribute to air and water pollution and are a significant source of methane leakage.

Long after they have ceased pumping oil or gas, well sites continue to leak in ways that are not always fixable. These leaks can include fluids and toxic vapors such as hydrogen sulfide and benzene, which imperil drinking water supplies and air quality and threaten public health in the communities where they are located. A June 2023 nationwide study of 81,857 orphaned wells—abandoned oil and gas wells for which no responsible party can be found—estimated that 4.6 million Americans live within 1 kilometer (.62 miles) of a documented orphaned well. Residents living near these sites face a wide range of risks; however, the authors of the study concluded that current environmental monitoring data are not extensive enough to fully characterize these risks.[220] (Note that databases of abandoned wells do not distinguish between those that have been hydraulically fractured and those that have not.)

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[218] Carly Cassella, "Elevated Radiation Found near US Fracking Sites Has Public Health Experts Worried," Science Alert, October 23, 2020, https://www.sciencealert.com/elevated-radiation-levels-discovered-near-us-fracking-sites-study-finds.

[219] Jacob A. Deighton et al., "Measurements Show That Marginal Wells Are a Disproportionate Source of Methane Relative to Production," *Journal of the Air & Waste Management Association* 70, no. 10 (2020): 1030–42, https://doi.org/10.1080/10962247.2020.1808115.

[220] Mary Kang et al., "Environmental Risks and Opportunities of Orphaned Oil and Gas Wells in the United States," *Environmental Research Letters* 18, no. 7 (July 1, 2023): 074012, https://doi.org/10.1088/1748-9326/acdae7.

Idle, abandoned, and orphaned wells are also a significant source of methane leakage into the atmosphere, and, based on findings from New York and Pennsylvania, may exceed cumulative total leakage from oil and gas wells currently in production in these states. Plugging abandoned wells can, but does not always, reduce methane emissions, and plugs themselves deteriorate over time. (A well is plugged when the wellbore is filled with cement or clay after debris and uncemented pipe is removed. See footnote 929.). An unplugged well is considered idle if it has not produced oil or gas for two or more years.) Further, countless abandoned wells are unmapped and their locations unknown. Many have no apparent owner.

Inactive wells left behind by industry during energy price downturns or after bankruptcy are growing in number across North America, are poorly monitored and, as conduits for toxic air pollution and fluid leakage, are health and safety threats. Some have exploded. As well casings deteriorate, methane gas can mix with gypsum rock to create deadly hydrogen sulfide gas.[221] State and federal policies that do not require companies to post bonds covering clean-up costs prior to the start of operations incentivize companies to delay plugging wells as long as possible. The largest owner of aging, depleted wells, Diversified Energy Company, is currently struggling with financial liabilities that exceed its assets by $300 million. Bankruptcy could leave taxpayers responsible for the cost of plugging its inventory of 70,000 wells.[222]

Of the nearly half million oil and gas wells in Alberta, Canada alone, 172,000 wells are inactive, decommissioned, or abandoned and in need of reclamation.[223] The amount of methane seeping from them is not known. The risk of leaks is known to increase inexorably as inactive wells age.[224, 225] As revealed in a pair of investigations, there is no systematic auditing or monitoring of sites that have been deemed reclaimed and mounting evidence to suggest that Alberta's inactive oil and gas wells are not reclaimed in the long run.[226, 227]

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[221] Chris Ensing, "Wheatley Explosion Could Be 'Tip of the Iceberg' in Ontario Given Number of Abandoned Wells: Expert," *CBC News*, September 2, 2021, https://www.cbc.ca/news/canada/windsor/wheatley-explosion-gas-wells-1.6161023.

[222] Kristina Marusic, "What Happens If the Largest Owner of Oil and Gas Wells in the US Goes Bankrupt?," *Environmental Health News*, January 26, 2023, https://www.ehn.org/abandoned-oil-and-gas-wells-2659296731.html.

[223] "Oil and Gas Liabilities Management," Alberta.ca, 2022, https://www.alberta.ca/oil-and-gas-liabilities-management.aspx.

[224] Sharon J. Riley, "Regulator Projects Alberta's Inactive Well Problem Will Double in Size by 2030, Documents Reveal," The Narwhal, April 8, 2019, http://thenarwhal.ca/regulator-projects-albertas-inactive-well-problem-will-double-in-size-by-2030-documents-reveal/.

[225] Alec Jacobson, "These Zombies Threaten the Whole Planet: Canada's Oil Patch Has Nearly 100,000 Suspended Wells, Neither Active nor Capped, and They're a Worrying Source of Planet-Warming Methane," *The New York Times*, October 30, 2020, https://www.nytimes.com/2020/10/30/climate/oil-wells-leak-canada.html?referringSource=articleShare.

[226] Sharon J. Riley, "Report 'Buried' by Alberta Government Reveals 'Mounting Evidence' That Oil and Gas Wells Aren't Reclaimed in the Long Run," *The Narwhal*, January 23, 2020, https://thenarwhal.ca/report-buried-by-alberta-government-reveals-mounting-evidence-that-oil-and-gas-wells-arent-reclaimed-in-the-long-run/.

[227] Sharon J. Riley, "Stonewalled: Alberta Ignored Warnings about Oil and Gas Cleanup, Ex-Government Scientist Says," March 20, 2022, https://thenarwhal.ca/alberta-oil-gas-wells-reclamation-scientist/.

The U.S. Environmental Protection Agency (EPA) estimates that 3.7 million inactive oil and gas wells are scattered across the United States, of which only 42 percent are plugged.[228] Pennsylvania alone is home to 200,000 to 750,000 old wells, most of which are not mapped or even visible on the surface.[229]

California has 124,000 abandoned oil and gas wells and 38,000 idle wells. That same EPA study measured methane emissions from a representative sample of abandoned oil and gas wells in California and found a wide range of leakage rates—with unplugged idle wells leaking more than plugged abandoned wells and with the worst culprits leaking enough to substantially impact California's methane budget. (See footnote 1497.) No state or federal agency routinely monitors methane leakage from abandoned and idle wells. (See footnotes 1537, 1542.) In September 2023, California passed the Orphaned Well Preventing Act (AB 1167) that prohibits the sale of an oil well unless the new owner can pay to plug and decommission it. At this writing, the governor has not yet signed the bill.[230]

Low prices for oil and gas throughout 2019 and 2020 triggered a 50 percent rise in oil and gas company bankruptcies and resulted in a further surge in abandoned and orphaned wells. The upfront bonds required of drillers to cover future cleanup and well plugging—a condition of receiving of permit to drill—are typically inadequate, shifting the full cost of remediation to state and federal taxpayers (See footnote 1500.) In 2019, the U.S. Government Accountability Office estimated a clean-up and plugging cost of $20,000 to $145,000 per abandoned well and projected a total of cost $60 billion to $435 billion to clean up all of the abandoned oil and gas wells in the United States. (See footnote 1514.) State and federal policies have further incentivized abandoning wells, rather than paying to plug them, by allowing marginal or idle wells to remain on the books as active wells even when they may be leaking more methane into the atmosphere than they are capturing. A 2021 *Bloomberg* investigation of idle wells in Ohio found methane leaks at most of the 44 sites visited by reporters, with 59 percent of sites leaking methane at levels sufficient to trigger a safety alarm.[231]

In November 2021, the bipartisan infrastructure package earmarked $4.7 billion for the plugging and remediation of abandoned or orphaned gas and oil wells, an indirect subsidy to the fracking industry. Almost two years later, state agencies are struggling to make use of these grants and implement effective plugging and remediation programs both because many orphaned wells remain undetected and because qualified work crews remain scarce with plugging contractors and oil and gas producers in competition for the same pool of skilled workers. In July 2023, the Department of Interior announced new rules for plugging old wells that require states to monitor

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[228] EPA, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021" (U.S. Environmental Protection Agency, May 9, 2023), https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2021.

[229] Mike Lee, "Millions of Abandoned Wells Spark Climate, Safety Fears," E&E News, May 20, 2019, https://web.archive.org/web/20190520165746/https://www.eenews.net/stories/1060364121.

[230] Ari Plachta, "Lawmakers Want to Put Oil Industry on the Hook to Plug Old Wells. Will Gavin Newsom Sign It?," *Sacramento Bee*, September 15, 2023, https://www.sacbee.com/news/politics-government/capitol-alert/article279260534.html.

[231] Zachary R. Mider and Rachel Adams-Heard, "An Empire of Dying Wells," *Bloomberg Green*, October 12, 2021, https://www.bloomberg.com/features/diversified-energy-natural-gas-wells-methane-leaks-2021/?cmpid=BBD101221_MKT&utm_medium=email&utm_source=newsletter&utm_term=211012&utm_campaign=markets&sref=kq5Tnm64.

methane emissions, check for groundwater contamination, and prioritize work in historically disadvantaged communities. These tracking requirements increase the cost of remediation and may ultimately lead to fewer wells being plugged.[232]

3) Fracking is accelerating the climate crisis.

Natural gas is 85-95 percent methane, a potent greenhouse gas. On the grounds that natural gas emits, when combusted, only 53 percent of the carbon dioxide emitted by coal, early promoters of fracking argued that natural gas could serve as a "bridge fuel" while renewable energy sources ramp up. An abundance of scientific evidence now disproves these claims and shows that natural gas is at least as damaging to the climate as coal and may be worse due to inevitable leaks of unburned methane. A July 2023 study found that a methane leakage rate of just 0.2 percent causes the warming potential of natural gas to exceed that of coal, which, when burned, forms sulfate aerosols that mask warming.[233, 234]

Recent research using satellites and aircraft reveal that fracking operations and their ancillary infrastructure are emitting significantly more methane than 0.2 percent and several times higher than the levels disclosed by the industry or estimated in federal greenhouse gas inventories.[235] The liquefaction and transportation of natural gas as LNG raises its greenhouse gas emissions even further, by another 30 percent, both because of the need for evaporative cooling and venting but also because flaring is used to control pressure during regasification.

Research also demonstrates that methane, while less persistent in the atmosphere than carbon dioxide, is a far more powerful greenhouse gas than formerly understood. The United Nations Intergovernmental Panel on Climate Change (IPCC) estimates that over a 20-year time frame—longer than the decade remaining to limit global warming to 1.5° C—methane can, pound for pound, trap 86 times more heat than carbon dioxide. (See footnote 1859.) Methane concentrations in the atmosphere have nearly tripled since pre-industrial times, with levels surging past 1,900 parts per billion by the end of 2021.[236]

Altogether, the science to date shows that methane is the biggest contributor to the ongoing failure to meet agreed-upon global emissions targets and stabilize the climate. According to the IPCC's Sixth Assessment Report, the first installment of which was released in 2021, methane has contributed nearly 40 percent of all global warming to date. The report devoted an entire

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[232] Shelby Webb, "States Struggle to Plug Oil Wells with Infrastructure Law Cash," *E&E EnergyWire*, July 14, 2023, https://www.eenews.net/articles/states-struggle-to-plug-oil-wells-with-infrastructure-law-cash/.
[233] Deborah Gordon et al., "Evaluating Net Life-Cycle Greenhouse Gas Emissions Intensities from Gas and Coal at Varying Methane Leakage Rates," *Environmental Research Letters*, July 4, 2023, https://doi.org/10.1088/1748-9326/ace3db.
[234] Hiroko Tabuchi, "Leaks Can Make Natural Gas as Bad for the Climate as Coal, a Study Says," *The New York Times*, July 13, 2023, https://www.nytimes.com/2023/07/13/climate/natural-gas-leaks-coal-climate-change.html.
[235] Terry Slavin, "Analysis: Benchmark of Big Oil on Methane Emissions Shows 'Significant Gap' between Reality and Reporting," Reuters, August 14, 2021, https://www.reuters.com/article/emissions-methane/analysis-benchmark-of-big-oil-on-methane-emissions-shows-significant-gap-between-reality-and-reporting-idUSMTZSPDEH8EU9J79K.
[236] Jeff Tollefson, "Scientists Raise Alarm over 'Dangerously Fast' Growth in Atmospheric Methane," *Nature*, February 8, 2022, d41586-022-00312–2, https://doi.org/10.1038/d41586-022-00312-2.

chapter to the problem of methane and potent heat-trapping gasses other than carbon dioxide. To avoid exceeding 1.5° C of global warming, the IPCC urged "strong, rapid, and sustained reductions" in methane emissions. (See footnote 45.) At the 2021 climate summit in Glasgow, 105 nations signed the Global Methane Pledge to cut methane emissions globally by 30 percent by 2030 in an attempt to limit warming to 1.5° C.

The call to curtail methane in order to stabilize the climate has been echoed by the both the U.N. Environment Programme (UNEP) and the International Energy Agency (IEA), which found that oil and gas operations around the world emit a level of methane that is equivalent to all the energy-related emissions of carbon dioxide from the European Union.[237] (See footnotes 1704, 2389.) According to a 2019 study, shale gas production in North America alone contributes more than half of all of the increased emissions from fossil fuels globally and at least one-third of the total increased emissions from all sources globally over the past decade. (See footnote 1741.) A 2021 study found that reductions in human-caused methane emissions alone, of which oil and gas wells are the single largest source, could avert nearly one-third of the global warming expected in the next two decades. (See footnote 1692.)

Multiple studies, using a range of methodologies, now also show that real-world methane leakage rates from North American drilling and fracking operations greatly exceed earlier EPA estimates and are likely driving the current surge in global methane levels. IEA's Global Methane Tracker 2023 found that the United States now leads the world in methane emissions from oil and gas operations.[238] Global methane emissions from the energy sector are about 70 percent greater than the amount national governments have officially reported, with North American methane emissions reported at 14.0 million tonnes (Mt), but estimated by the IEA to be 20.9 Mt.[239] An April 2023 study shows that 15 percent of the world's gas- and oil-derived methane emissions are contributed by the United States. (See footnote 1672.)

Methane escapes into the atmosphere from all parts of the extraction, processing, and distribution system—for both oil and gas—all the way to the burner tip. In the heavily drilled Barnett Shale of northeastern Texas, methane emissions were shown to be 50 percent higher than the EPA had estimated. Fracking operations and associated infrastructure contributed 71-85 percent of the methane emissions in the region. A 2018 analysis of methane leaks from the entire U.S. oil and gas supply chain found leakage rates were 60 percent higher than reported by the EPA, and a 2019 study in southwestern Pennsylvania found shale gas emissions that were underreported by a factor of five when compared to EPA estimates. (See footnotes 1741, 1776.) A 2021 study of the intensely drilled and fracked Uinta Basin in northern Utah found that 6 to 8 percent of the total gas extracted escaped as atmospheric emissions, a shockingly high leakage rate that remained constant between 2015 and 2020, even as gas production in the region declined over the same period. (See footnote 1681.)

[237] International Energy Agency, "Methane Tracker 2021" (IEA, January 2021), https://www.iea.org/reports/methane-tracker-2021.
[238] International Energy Agency, "Global Methane Tracker 2023," February 2023, https://www.iea.org/reports/global-methane-tracker-2023.
[239] International Energy Agency, "Methane Tracker 2022" (IEA, February 2022), https://www.iea.org/reports/global-methane-tracker-2022/overview.

The Permian Basin in West Texas and eastern New Mexico—the world's largest shale deposit for oil and gas—accounts for more than 40 percent of total U.S. oil extraction and 22 percent of gas extraction each year.[240] According to a 2020 study using satellite observations, methane leakage from drilling and fracking activities in the Permian is two times higher than previously estimated and is now thought to contribute half of the methane emissions from all U.S. oil- and gas-producing regions, with newer wells and associated flaring operations a major culprit. (See footnote 1710.) A 2022 study found that 9.4 percent of gas production in New Mexico's Permian basin escaped into the atmosphere, a leakage rate that is 6.7 times higher than the EPA estimate.[241] A July 2023 study that collected aerial measurements at 7,474 oil and gas wells across the basin confirmed the importance of previously underreported emissions sources in the Permian Basin.[242] Halting methane emissions from the Permian could do more to slow climate change than almost any other single measure.

An August 2023 study using satellite observations found that methane emissions from oil and gas extraction activities are 30 percent higher than the global totals submitted to the United Nations Framework Convention on Climate Change as part of mandated reporting by nation states. Most of this discrepancy is attributable to under-reporting by the world's four largest emitters: the United States, Russia, Venezuela, and Turkmenistan.[243]

Much of the methane emitted from drilling and fracking activities and associated infrastructure originates not from accidental leaks but from purposeful losses that are inherent in the design of the industry's machinery or to normal operating use and are, therefore, not possible to mitigate. (See footnotes 2045-2047.) Methane is vented into the atmosphere during routine maintenance on compressor stations and pipelines; to create evaporative cooling for LNG storage and transport; during the flowback period after a well is fracked; and as an emergency procedure to control pressures.

Malfunctioning and unlit flare stacks are a major culprit. Research from Texas comparing satellite measurements with data on flaring volumes collected in state databases reveal that mass venting of raw gas into the atmosphere is much higher than reported, with methane emissions exceeding 3 percent of production rather than the widely presumed 1-2 percent. (See footnotes 513, 514.) In three Texas shale basins, unlit flares and inefficient flaring are responsible for a fivefold increase in methane emissions above present assumptions and, taken together, constitute 4 to 10 percent of total U.S. oil and gas methane emissions.

Inactive, abandoned wells and liquid storage tanks are also significant emitters of methane. (See footnote 1682.) A 2022 study found significant tank-related methane releases at twelve of fifteen

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[240] Olga Popova and Gary Long, "Advances in Technology Led to Record New Well Productivity in the Permian Basin in 2021," Today in Energy (U.S. Energy Information Administration, September 30, 2022), https://www.eia.gov/todayinenergy/detail.php?id=54079.
[241] Zachary R. Mider, "The Methane Hunters," *Bloomberg Businessweek + Green*, August 20, 2021, https://www.bloomberg.com/features/2021-methane-hunters-climate-change/.
[242] William M. Kunkel et al., "Extension of Methane Emission Rate Distribution for Permian Basin Oil and Gas Production Infrastructure by Aerial LiDAR," *Environmental Science & Technology*, August 10, 2023, acs.est.3c00229, https://doi.org/10.1021/acs.est.3c00229.
[243] Lu Shen et al., "National Quantifications of Methane Emissions from Fuel Exploitation Using High Resolution Inversions of Satellite Observations," *Nature Communications* 14, no. 1 (August 16, 2023): 4948, https://doi.org/10.1038/s41467-023-40671-6.

shale gas well pads monitored in in West Virginia with optical gas imaging cameras. (See footnote 1675.) Methane leakage at the levels now being documented, using multiple approaches in measurement and modeling, negates previously hypothesized benefits from burning methane instead of coal in most existing power plants. Trading coal plants for gas plants does not reduce cumulative lifetime carbon emissions when upstream methane leaks are factored in. (See footnote 2210.)

Rising methane levels in the atmosphere make increasingly difficult the urgent task of limiting global warming to below levels called for in the Paris Agreement, which was based on older presumptions that global methane levels had plateaued. Instead, methane levels began to rise in 2007 and then shot up sharply in 2014, a time period that corresponds to a massive increase in the use of fracking in North America.

Indeed, increasing evidence points to fossil fuels in general, and fracking in particular, as the main driver of this surge. Isotopic analysis identifies shale gas production as the source of at least one-third of the total increased emissions from all sources globally and the source of more than half of the increased emissions from fossil fuels globally. These results suggest that the North American fracking boom is a major culprit of the ongoing rise in atmospheric methane levels. (See footnotes 1748, 1755, 1777.)

4) Fracking contaminates and depletes drinking water sources.

Many instances of drinking water sources contamination by drilling and fracking activities, or by associated waste disposal, exist. As identified by the EPA in 2016, water contamination occurs through three confirmed pathways: spills; discharge of fracking waste into rivers and streams; and underground migration of chemicals, including gas, into drinking water wells.

Methane and fracking-related contaminants can reach drinking water sources through cracks in well casings, through spaces between the casing and the wellbore, through naturally occurring fractures and fissures connecting shale layers with aquifers, and through abandoned wells. Methane migration into drinking water aquifers can change water chemistry in ways that mobilize metals or release hydrogen sulfide. (See footnote 701.)

In June 2020, the attorney general of Pennsylvania announced 15 criminal counts related to fracking activities in northeastern Pennsylvania, including nine felony charges, filed against Cabot Oil and Gas stemming from violations of the state's Clean Streams Law. According to the grand jury's report, "We find that, over a period of many years, and despite mounting evidence, Cabot Oil and Gas failed to acknowledge and correct conduct that polluted Pennsylvania water through stray gas migration."[244] The charges were part of a two-year grand jury investigation into environmental crimes committed by fracking companies that focused on contamination of

[244] Susan Phillips, "Pa. Attorney General Charges Cabot Oil and Gas with Environmental Crimes," State Impact Pennsylvania, June 15, 2020, https://stateimpact.npr.org/pennsylvania/2020/06/15/pa-attorney-general-charges-cabot-oil-and-gas-with-environmental-crimes/.

private well water with high levels of methane and metals, as well as damage to public health.[245, 246] In November 2022, Coterra Energy (formerly Cabot) pleaded no contest to these charges and agreed to pay $16.29 million for a new public water line. Coterra also agreed to pay the water bills of affected residents for 75 years.[247, 248]

A second company, Range Resources, pleaded no contest to environmental crimes at two sites in southwestern Pennsylvania involving leaks and spills that contaminated surface water and groundwater.[249] In its report, the grand jury also criticized Pennsylvania's Department of Health for failure to collect data and act on health complaints and denounced the state's Department of Environmental Protection for its "culture of inadequate oversight" that resulted in harm to public health and the environment.

Researchers working in Texas found 19 different fracking-related contaminants—including cancer-causing benzene—in hundreds of drinking water samples collected from the aquifer overlying the heavily drilled Barnett Shale, thereby documenting widespread water contamination.

Similarly, researchers working in Susquehanna County, Pennsylvania found chemical additives known to be ingredients in fracking fluid as well as chemicals associated with fracking wastewater in private drinking water wells near fracking operations and in nearby lakes, springs, and ponds. (See footnote 681.) Also in Pennsylvania, a solvent used in fracking fluid was found in drinking water wells near drilling and fracking operations known to have well-casing problems. Fracking waste discharged to rivers and streams has led to elevated levels of brominated and iodinated disinfection byproducts that are particularly toxic and "raise concerns regarding human health." (See footnote 739.)

In New Mexico a shift from conventional drilling to fracking triggered dramatic increases in groundwater contamination with dissolved solids, sodium, and calcium, with levels of contaminants correlated with density of oil wells.

In California, state regulators admitted that they had mistakenly allowed oil companies to inject drilling wastewater into aquifers containing clean, potable water. (See footnotes 802, 803.)

A 2021 Physicians for Social Responsibility (PSR) investigation revealed that the EPA had, ten years earlier and over the objections of its own staff scientists, approved the use of chemicals for oil and gas drilling and/or fracking that the scientists feared could degrade into highly toxic per-

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[245] Office of the Attorney General, Commonwealth of Pennsylvania, "AG Shapiro and 43rd Statewide Grand Jury," press release, June 15, 2020, https://www.attorneygeneral.gov/taking-action/press-releases/ag-shapiro-and-43rd-statewide-grand-jury-file-criminal-charges-against-nepa-fracking-company/.
[246] Office of the Attorney General, Commonwealth of Pennsylvania, "Report 1 of the Forty-Third Statewide Investigating Grand Jury," June 15, 2020, https://www.attorneygeneral.gov/wp-content/uploads/2020/06/FINAL-fracking-report-w.responses-with-page-number-V2.pdf.
[247] Pennsylvania Attorney General, "AG Shapiro Announces Plea, Public Water Line Construction for Victims of Cabot Oil & Gas [Press Release]," November 29, 2022, https://www.attorneygeneral.gov/taking-action/ag-shapiro-announces-plea-public-water-line-construction-for-victims-of-cabot-oil-gas/.
[248] Pennsylvania Attorney General.
[249] Reid Frazier and Susan Phillips, "Pa. Grand Jury Report on Fracking: DEP Failed to Protect Public Health," State Impact Pennsylvania, June 25, 2020, https://stateimpact.npr.org/pennsylvania/2020/06/25/pa-grand-jury-report-on-fracking-dep-failed-to-protect-peoples-health/.

and polyfluoroalkyl substances (PFAS, or so-called "forever chemicals"). PSR also found that oil and gas companies had used PFAS—or chemicals that could break down into PFAS in at least 1,200 wells in six U.S. states (Louisiana, Arkansas, New Mexico, Texas, Oklahoma, and Wyoming). Extensive use of chemical trade secret claims and other lax chemical disclosure rules prevented PSR researchers from determining whether any of the 1,200 wells were injected with the same chemicals approved by the EPA. PFAS chemicals are linked to cancer and birth defects at vanishingly low concentrations, are known to contaminate drinking water sources, and do not break down in the environment. (See footnotes 653, 654.) A follow-up analysis of public data by the *Philadelphia Inquirer* identified the use of PFAS in at least eight Pennsylvania fracking wells between 2012 and 2014.[250] Building on the multi-state report, data unearthed by PSR reveals that PFAS have, since 2008, also been used in fracking operations in at least ten counties in Colorado, six counties in New Mexico, and 73 counties in Texas.[251] (See footnotes 632, 633.)

Fracking also threatens drinking water supplies through water depletion, especially in arid regions. According to a 2019 report, the volume of water used for fracking U.S. oil wells has more than doubled since 2016. (See footnote 698.) Oil and gas operations in the arid Permian Basin used eight times more water for fracking in 2018 than they did in 2011, threatening groundwater supplies. (See footnote 7.) In Arkansas, researchers found that water withdrawals for fracking operations deplete streams used for drinking water and recreation. (See footnote 728.)

With increasing volumes of wastewater now exceeding the storage capacity for underground injection wells—and with underground injection linked to earthquake risk—Texas and Colorado are now petitioning the EPA to allow release of fracking wastewater into rivers and streams and to allow its use for irrigation and watering livestock. These practices further imperil drinking water sources.[252]

The trend toward mega-fracking, with longer and more extensive horizontal wellbores per well pad, coupled with the ongoing proliferation in the number of wells, has pushed the demand for water use in fracking operations ever higher, exacerbating both the problem of drinking water depletion and the problem of how to dispose of ever-increasing amounts of toxic fracking wastewater. A 2018 study found that water used for U.S. fracking operations increased by 770 percent per well between 2011 and 2016, while the amount of wastewater generated increased by 1,440 percent. (See footnote 712.)

This trend has continued. A September 2023 investigation by the *New York Times* found that water demand for fracking operations is surging as individual fracks use more and more water per well. In Texas, even as many communities have instituted water restrictions in the face of falling water tables and prolonged drought, water use by fracking industry is neither monitored

[250] Editorial Board, "Fracking in Pennsylvania Used Toxic 'Forever Chemicals' as Pa. Officials Maintain Willful Ignorance," *The Philadelphia Inquirer*, October 5, 2021, https://www.inquirer.com/opinion/editorials/fracking-pennsylvania-pfas-toxic-chemicals-water-20210805.html.
[251] Dusty Horwitt, Barbara Gottlieb, and Gary Allison, "Fracking with 'Forever Chemicals' in Colorado" (Physicians for Social Responsibility, January 2022), https://www.psr.org/wp-content/uploads/2022/01/fracking-with-forever-chemicals-in-colorado.pdf.
[252] Paul Stinson, "Texas, Oklahoma Want More Say in Handling Fracking Wastewater," Bloomberg Law, August 15, 2019, https://news.bloomberglaw.com/environment-and-energy/texas-oklahoma-want-more-say-in-handling-fracking-wastewater.

nor rationed. In 2010, a horizontally fracked well in the Permian Basin was, on average, less than 4,000 feet, whereas, by 2022, average well length had expanded to more than 10,000 feet and requires far more water. Altogether, in the United States, fracking has collectively used up 1.5 trillion gallons of water since 2011. This water is no longer part of the hydrologic cycle.[253]

5) Fracking creates air pollution at levels known to harm health.

More than 200 airborne chemical contaminants have been detected near drilling and fracking sites. Of these, 61 are classified as hazardous air pollutants, including carcinogens; 26 are endocrine-disrupting compounds that have been linked to reproductive, developmental, and neurological damage. In addition to the wells themselves, the sources of these air pollutants include a wide range of equipment, including condensate tanks, wastewater pits, and flare stacks. (See footnotes 528, 541.) Sources of methane emissions, which are located throughout the oil and gas supply chain, are nearly always also sources of other health-damaging air pollutants.[254]

Drilling and fracking operations emit fine particles, including soot from diesel exhaust; volatile organic air pollutants, including benzene and formaldehyde; and nitrogen oxides that combine to create ground-level ozone (smog) even in otherwise rural regions. Elevated levels of fine particle emissions from fracking well pads have been measured at distances of more than four miles. (See footnote 516.) Exposure to these pollutants is known to cause premature death, exacerbate asthma, and contribute to poor birth outcomes and increased rates of hospitalization and emergency room visits. During the 2020 lockdown period of the COVID-19 pandemic, which caused a historic collapse in oil and gas demand, nitrogen dioxide emissions plunged by 30 percent in the Permian Basin, revealing the significant contribution of drilling and fracking operations to smog creation.[255]

An October 2023 study documented episodically high levels of chlorine emissions—with spikes that exceeded the highest inland chlorine gas concentration ever measured—in a rural area in the middle of the intensely fracked Eagle Ford Shale gas field in southeastern Texas. Likely sources include hydrochloric acid and other chlorinated biocides added to fracking fluid as well as the chloride-rich brine that flows up from the geological formation during fracking operations. Chlorine gas is highly reactive and quickly oxidizes volatile organic compounds to create smog

[253] Hiroko Tabuchi and Blacki Migliozzi, "'Monster Fracks' Are Getting Far Bigger. And Far Thirstier.," *New York Times*, September 25, 2023, https://www.nytimes.com/interactive/2023/09/25/climate/fracking-oil-gas-wells-water.html?smid=nytcore-ios-share&referringSource=articleShare.
[254] Drew Michanowicz et al., "Methane and Health-Damaging Air Pollutants from the Oil and Gas Sector: Bridging 10 Years of Scientific Understanding," Technical Report (PSE Healthy Energy, October 2021), https://www.psehealthyenergy.org/our-work/publications/archive/methane-and-health-damaging-air-pollutants-from-the-oil-and-gas-sector-bridging-10-years-of-scientific-understanding/.
[255] Raquel Serrano-Calvo et al., "COVID-19 Impact on the Oil and Gas Industry NO_2 Emissions: A Case Study of the Permian Basin," *Journal of Geophysical Research: Atmospheres* 128, no. 13 (July 16, 2023): e2023JD038566, https://doi.org/10.1029/2023JD038566.

and a variety of secondary organochlorinated air pollutants, many of which are known to be highly toxic.[256]

The production phase of drilling and fracking operations—when the raw gas or oil is flowing from the well—typically emits the highest levels and most complex mixtures of hazardous air pollutants over the longest period of time. A 2021 study that quantified ozone precursor emissions from oil and gas extracting regions across the United States found that volatile organic pollutants and nitrogen oxides from oil and gas basins are three times higher than current estimates. (See footnote 493.) In the Permian Basin, levels of hydrogen sulfide gas from drilling and fracking operations can exceed legal limits in the ambient air of communities near drilling and fracking operations. (See footnote 510, 511.) In California's San Joaquin Valley, evaporation from liquid waste pits is a significant source of benzene, toluene, ethylbenzene, and xylene. (See footnote 515.)

Of the lower 48 states, six states (Texas, Oklahoma, Colorado, North Dakota, West Virginia, and Pennsylvania) produce nearly 70 percent of the nation's natural gas and over 74 percent of its onshore crude oil. These six states experience the highest levels of ground-level ozone and fine particle pollution attributable to oil and gas extraction activities.

Volatile organic compounds (VOCs) from drilling and fracking operations, together with nitrogen oxides, are responsible for 17 percent of locally produced ozone in Colorado's heavily drilled Front Range. (See footnote 555.) Colorado has exceeded federal ozone limits for the past decade, a period that corresponds to a boom in oil and gas drilling (See footnote 553.) Air pollution near drilling and fracking operations is high enough in some Colorado communities to raise cancer risks, according to a 2018 study. (See footnote 540.) A 2021 study found that the fracking boom in northeastern Colorado was a significant source of toxic and smog-making air pollutants, including benzene and toluene. (See footnote 505.)

Living near drilling and fracking operations significantly increases asthma attacks for residents of Pennsylvania. Those living near active gas wells are 1.5 to 4 times more likely to suffer from asthma attacks than those living farther away, with the closest group having the highest risk. (See footnotes 1213, 1214.)

In California, fracking occurs disproportionately in areas already suffering from serious air quality problems and can drive ozone and other federally regulated air pollutants to levels that violate air quality standards. (See footnotes 566, 567.) This increased air pollution and smog formation pose a serious risk to all those already suffering from respiratory issues, such as children with asthma. With an average of 203 high-ozone days a year, intensely fracked Kern County, California is the fifth-most ozone-polluted county in the nation, according to the American Lung Association. In California, air monitoring data shows that living near oil and gas wells increases the exposure of nearby residents to levels of air pollutants sufficient to harm health, with Black and Latino communities disproportionately affected. (See footnote 492.)

Several studies have documented a sharp uptick in atmospheric ethane, a gas that co-occurs with methane and whose presence is attributable to emissions from oil and gas wells. This trend

[256] Catherine G. Masoud et al., "High Chlorine Concentrations in an Unconventional Oil and Gas Development Region and Impacts on Atmospheric Chemistry," *Environmental Science & Technology*, October 2, 2023, acs.est.3c04005, https://doi.org/10.1021/acs.est.3c04005.

reverses a previous, decades-long decline. Ethane is a potent precursor to ground-level ozone. (See footnotes 525, 557, 559.)

The United States leads the world in the number of drill site **flaring operations**. Flares are used to control pressure but, more frequently, to burn off natural gas as waste during oil drilling in places that lack infrastructure for gas capture and transport. The ongoing boom in domestic oil production enabled by fracking has caused natural gas flaring to proliferate. Emissions from flare stacks contribute to ozone creation and include several carcinogens, notably benzene and formaldehyde. Flaring also releases carbon monoxide, carbon black, and toxic heavy metals. In 2016, the EPA acknowledged that it had dramatically underestimated health-damaging air pollutants from flaring operations. (See footnotes 551, 552.) A 2017 study of plume samples from gas flares in North Dakota found that incomplete combustion from flaring is responsible for 20 percent of the total emissions of methane and ethane from the Bakken shale fields—more than double the expected value. (See footnote 547.)

Studies in the Eagle Ford Shale region of Texas show that flaring is the dominant source of exposure to nitrogen oxide air pollutants in rural areas. (See footnote 531.) In the Texas Permian oil basin, more than two-thirds of flares (69-84 percent) are operating without state permits.[257, 258] In North Dakota, hospitalizations for respiratory distress increase with increases in flaring activity, with effects seen in people living up to 60 miles away. (See footnote 490.)

6) Public health problems associated with fracking include prenatal harm, respiratory impacts, cancer, heart disease, mental health problems, and premature death.

Fracking is linked to numerous health problems, up to and including early death. A 2022 study using data gathered from more than 15 million Medicare recipients found that older citizens living near fracking sites were at higher risk for dying early than those living in areas without fracking. (See footnote 1130.) According to a 2023 assessment, the air pollution from oil and gas extraction operations alone is responsible for $77 billion in yearly health impacts, which include 410,000 asthma attacks, 2,200 new cases of childhood asthma, and 7,500 excess deaths.[259]

Poor birth outcomes have been linked to fracking activities in multiple studies in multiple locations using a variety of methods. Studies of mothers living near oil and gas extraction operations consistently find impaired infant health, especially elevated risks for low birth weight and preterm birth. A 2022 Canadian study of 35,000 pregnancies in rural Alberta found that babies born to mothers living near fracking wells had increased incidence of low birth weight, premature birth, and major congenital abnormalities. (See footnote 1128.)

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[257] Jack McDonald and Sharon Wilson, "Flaring in Texas: A Comprehensive Government Failure" (Earthworks, August 2021), https://41p14t2a856b1gs8ii2wv4k4-wpengine.netdna-ssl.com/assets/uploads/2021/08/Flaring-in-Texas-FINALsm.pdf.
[258] Valerie Volcovici and Nichola Groom, "Most Flares from Texas Permian Oil Drilling Lack Permits -Study," Reuters, August 19, 2021, https://www.reuters.com/business/energy/most-flares-texas-permian-oil-drilling-lack-permits-study-2021-08-19/.
[259] Jonathan J Buonocore et al., "Air Pollution and Health Impacts of Oil & Gas Production in the United States," *Environmental Research: Health* 1, no. 2 (June 1, 2023): 021006, https://doi.org/10.1088/2752-5309/acc886.

A 2020 study of pregnant women living in the Eagle Ford Shale area of Texas found that exposure to oil and gas flaring was associated with a 50 percent increase in the risk of preterm birth.[260] (See footnotes 1148, 1149.) A 2020 study of pregnant women in California's San Joaquin Valley found that mothers with the highest exposure to oil and gas wells were 8 to 14 percent more likely to experience a preterm birth. These risks were especially pronounced for Black and Hispanic women. (See footnote 1150.) Another 2020 study found that living near active oil and gas wells during pregnancy increased the risk of low-birthweight babies born to mothers throughout California. (See footnote 1152.)

A 2023 study conducted by the Pennsylvania Department of Health and a University of Pittsburgh research team found that babies born to mothers who lived near active gas wells, compressor stations, or fracking waste facilities in eight counties in Southwestern Pennsylvania were significantly smaller at birth.[261] These findings corroborate a 2017 study that examined birth certificates for all 1.1 million infants born in Pennsylvania between 2004-2013 and found indicators of poorer infant health and significantly lower birth weights among babies born to mothers living near fracking sites. (See footnote 1203.) Another Pennsylvania study found a 40 percent increase in the risk of preterm birth among infants born to mothers who lived near active drilling and fracking sites, while an Oklahoma study and two Colorado studies variously found elevated incidences of neural tube defects and congenital heart defects. The newer studies add to existing evidence on poor birth outcomes related to fracking. (See footnotes 1170, 1183, 1189, 1241.)

A 2017 pilot study in British Columbia found elevated levels of muconic acid—a marker of exposure to the carcinogen benzene—in the urine of pregnant women living near fracking sites. (See footnote 1204.) A 2019 study of pregnant Indigenous women living near fracking sites in British Columbia found elevated levels of the developmental toxicants barium and strontium in their hair and urine. (See footnote 1174.) A 2020 study found that the air inside the homes of 85 pregnant women living close to fracking operations in British Columbia had higher levels of volatile organic compounds, including chloroform and acetone, compared with the general population. Further, greater well density was linked to increased exposure. Proximity to fracking operations was inconsistently linked to preterm birth and smaller birthweights. (See footnote 1129. See also footnote 1150.)

Prenatal health risks from fracking operations extend to mothers as well as their infants. A 2021study of more than 3 million pregnant women in Texas showed that living near an active oil or gas well increased the risks for high blood pressure and eclampsia. See footnote 1133.

An emerging body of evidence from both human and animal studies shows harm to fertility and reproductive success from exposure to oil and gas operations, at least some of which may be linked to the dozens of known endocrine-disrupting chemicals used in hydraulic fracturing.

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[260] Wendee Nicole, "On Wells and Wellness: Oil and Gas Flaring as a Potential Risk Factor for Preterm Birth," *Environmental Health Perspectives* 128, no. 11 (November 23, 2020), https://doi.org/10.1289/EHP7952.
[261] University of Pittsburgh School of Public Health, "Hydraulic Fracturing Epidemiology Research Studies: Birth Outcomes" (Pennsylvania Department of Health, Bureau of Epidemiology, July 31, 2023), https://paenv.pitt.edu/assets/Report_Birth_outcomes_Revised_2023_July.pdf.

Fracking is linked to cancer in children. A 2022 paper found a two- to three-fold increase in leukemia among children in Pennsylvania who lived near a fracking well during early life—or while their mothers were pregnant with them. (See footnote 1127.) Similarly, a 2017 Colorado study found higher rates of leukemia among children and young adults living in areas dense with oil and gas wells, while a Yale University research team reported that carcinogens involved in fracking operations had the potential to contaminate both air and water in nearby communities in ways that may increase the risk of childhood leukemia. The Yale team identified 55 known or possible carcinogens that are known to be used in fracking operations and that may be released into the air and water. Of these, 20 are linked to leukemia or lymphoma. (See footnotes 1209, 2497.)

In 2019, the *Pittsburgh Post-Gazette* documented 27 cases of Ewing's sarcoma, a rare bone cancer that tends to strike young people, in four counties in southwestern Pennsylvania that are at the center of the Marcellus Shale fracking boom.[262] Six cases occurred in the same school district. (The typical rate is 250 cases of Ewing's sarcoma per year in the United States as a whole. The cancer has no known cause.) There are also high numbers of other childhood cancers in the region, which is home to several polluting legacy industries. The Pennsylvania Department of Health reported "no conclusive findings" of a cancer cluster in the Canon-McMillan School District and Washington County, but as additional cases came to light, calls for more comprehensive investigations grew louder.[263, 264, 265, 266, 267] In November 2019, Governor Tom Wolf announced funding for two additional three-year studies.[268] In August 2023, the Pennsylvania Department of Health and the University of Pittsburgh reported no association between fracking activity and Ewing's sarcoma. However, this same study found that children

[262] Eliza Griswold, "When the Kids Started Getting Sick," *The New Yorker*, March 2, 2021, https://www.newyorker.com/news/dispatch/when-the-kids-started-getting-sick.
[263] David Templeton and Don Hopey, "CDC, State Officials Investigating Multiple Cases of Rare Cancer in Southwestern Pa.," *Pittsburgh Post-Gazette*, March 28, 2019, https://www.post-gazette.com/news/health/2019/03/28/Ewing-sarcoma-Washington-Westmoreland-cancer-Canon-McMillan-school-cecil-pennsylvania/stories/201903280010.
[264] David Templeton, "No Ewing Sarcoma Cluster in the Canon–McMillan School District, State Says," *Pittsburgh Post-Gazette*, April 23, 2019, https://www.post-gazette.com/news/health/2019/04/23/Ewing-sarcoma-cluster-Canon-McMillan-Pennsylvania-Health-Department/stories/201904230128.
[265] Meghan Schiller, "Families Affected by Rare Cancer Demand Answers after Pa. Health Dept. Investigation Results in 'No Conclusive Findings,'" KDKA2 CBS Pittsburgh, April 24, 2019, https://pittsburgh.cbslocal.com/2019/04/24/families-demand-answers-pa-health-dept-cancer-cluster-findings/.
[266] David Templeton and Don Hopey, "The Human Toll—Risk and Exposure in the Gas Lands," *Pittsburgh Post-Gazette*, May 14, 2019, https://newsinteractive.post-gazette.com/blog/childhood-cancer-pittsburgh-pennsylvania-canon-mcmillan-pollution/.
[267] The Editorial Board, "Young Lives at Stake: Rural Areas Deserve Answers on Child Cancers," *Pittsburgh Post-Gazette*, May 22, 2019, https://www.post-gazette.com/opinion/editorials/2019/05/22/childhood-cancer-pittsburgh-pennsylvania-canon-mcmillan-pollution-rural-areas-greene-fayette-washington-westmoreland/stories/201905220064.
[268] Eric T. Chaffin, "Pennsylvania Governor Funds Research Examining Potential Fracking Health Impacts," Pittsburgh Injury Law News, January 27, 2020, https://pittsburgh.legalexaminer.com/environment/pennsylvania-governor-funds-research-examining-potential-fracking-health-impacts/.

who lived within a mile of one or more fracking wells in Southwestern Pennsylvania had a five- to seven-fold risk of lymphoma.[269, 270, 271]

Other documented adverse health indicators among residents living near drilling and fracking operations variously include exacerbation of asthma as well as increased rates of hospitalization, ambulance runs, emergency room visits, self-reported respiratory problems and rashes, motor vehicle fatalities, trauma, drug abuse, and gonorrhea. According to a 2017 study, Pennsylvania residents with the highest exposure to active fracked gas wells were nearly twice as likely to experience a combination of migraine headaches, chronic nasal and sinus symptoms, and severe fatigue. (See footnote 1211.)

Similarly, a 2020 study that used a novel method of quantifying exposures found that respiratory, neurological, and muscular symptoms tracked with cumulative well density around residential areas in southwestern Pennsylvania. (See footnote 1147.) A 2020 study in Texas documented a link between intensity of drilling and fracking activities and frequency of hospitalization for childhood asthma. (See footnote 1146.) An August 2023 study in Southwest Pennsylvania found that people with asthma who lived near fracking wells had a four- to five-times greater risk of having an asthma attack. The research team found a strong link between living near gas wells and "severe exacerbations, emergency department visits, and hospitalizations for asthma."[272]

As demonstrated in multiple studies, mental health problems linked to living near drilling and fracking operations include depression, anxiety, and trauma. (See "Noise pollution, light pollution, and stress.")

Accumulating evidence shows connections between proximity to fracking sites and cardiovascular disease. In 2020, a major study of more than 12,000 heart failure patients in Pennsylvania showed that those living near fracking sites were significantly more likely to become hospitalized. The results also showed strong associations between fracking activity and two types of heart failure. "These associations can be attributed to the environmental impacts of fracking, including air pollution, water contamination, and noise, traffic, and community impacts." (See footnotes 1142, 1143.)

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[269] University of Pittsburgh School of Public Health, "Hydraulic Fracturing Epidemiology Research Studies: Childhood Cancer Case-Control Study" (Pennsylvania Department of Health, Bureau of Epidemiology, August 3, 2023), https://paenv.pitt.edu/assets/Report_Cancer_outcomes_2023_August.pdf.

[270] Jon Hurdle, "Fracking Linked to Increased Cases of Lymphoma in Pennsylvania Children, Study Finds," *Inside Climate News*, August 16, 2023, https://insideclimatenews.org/news/16082023/pennsylvania-fracking-link-childhood-lymphoma/.

[271] Anya Litvak and Hanna Webster, "'Is It Safe to Live Here?': Questions Loom at Presentation of Reports on Fracking and Health in Southwestern Pa.," *Pittsburgh Post-Gazette*, August 16, 2023, https://www.post-gazette.com/news/health/2023/08/15/shale-gas-fracking-health-studies/stories/202308150112.

[272] University of Pittsburgh School of Public Health, "Hydraulic Fracturing Epidemiology Research Studies: Asthma Outcomes" (Pennsylvania Department of Health, Bureau of Epidemiology, July 31, 2023), https://paenv.pitt.edu/assets/Report_Asthma_outcomes_revised_2023_July.pdf.

7) Health and safety risks for workers are severe and employment promises unrealized.

Drilling and fracking operations are exempt from federal Occupational Safety and Health Administration (OSHA) standards designed to prevent catastrophic releases of toxic, flammable, or explosive chemicals in workplaces. They are also exempt from OSHA rules written for the construction industry designed to prevent falls and other accidents on the job. Although announced by the agency in 1983 as forthcoming, federal safety regulations for the oil and gas industry have never materialized.[273, 274] Instead, inspectors can only apply the "general duty clause" which is widely recognized as grossly inadequate for an industry with unique hazards and a fatality rate far above the national average.

From 2008–2017, 1,038 oil and gas extraction workers were killed on the job, resulting in an annual fatality rate more than six times higher than the rate among all U.S. workers during that period.[275] From 2018 through 2020, 242 more oil and gas workers were killed. This includes 2020 fatality numbers showing 44 oil and gas extraction worker deaths.[276] In 2021, the year covered by the most recent edition of the AFL-CIO's "Death on the Job: The Toll of Neglect" report, 58 oil and gas extraction workers died on the job, accounting for 61 percent of the fatal work injuries in the mining sector, which overall continues to have fatality rate at least four times the national average. (See footnote 1011.) Vehicular accidents are the leading cause of worker deaths in the oil and gas extraction industry. Two-thirds of workers report workday shifts of 12 hours or more.

Studies in specific states, as well as some national studies, have provided additional details on regional rates and circumstances of injuries and deaths. Fatality rates among workers in the oil and gas extraction sector in North Dakota were seven times the national fatality rates in this industry, which itself has more deaths from fires and explosions than any other private industry. An increase in workplace deaths likewise accompanied the initial fracking boom period in West Virginia. On January 22, 2018, a natural gas rig exploded in southeastern Oklahoma, killing five workers trapped inside the driller's cabin. (See footnotes 1043, 1044, 1048.) The U.S. Chemical Safety Board determined that two preventive barriers designed to prevent uncontrolled gas blowouts had failed as a consequence of significant lapses in safety protocols and further discovered that "there is no guidance to ensure that an emergency evacuation option is present onboard these rigs or can protect workers in the driller's cabin from fire hazards." (See footnotes 1034 and 1040.)

In 2014, the National Institute for Occupational Safety and Health (NIOSH) began to collect detailed information about the locations and circumstances related to deaths of workers in oil and gas extraction. In two consecutive reports, covering 2015-2016 and then 2017, Texas had the

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[273] Corey Jones, "OSHA Standards Moot in Quinton Rig Explosion Because of Exemption for Oil-and-Gas Industry," *Tulsa World*, February 3, 2018, http://www.tulsaworld.com/news/state/osha-standards-moot-in-quinton-rig-explosion-because-of-exemption/article_162d0efa-7860-5f4b-b982-ebdeb142c075.html.
[274] Mike Lee, "Feds: Deadliest Drilling Accident in a Decade 'Preventable,'" E&E News, June 13, 2019, https://web.archive.org/web/20190613185313/https://www.eenews.net/stories/1060564501.
[275] Oil and Gas Extraction Program, "Oil and Gas Extraction: Burden, Need & Impact," National Institute for Occupational Safety and Health, November 30, 2018, https://www.cdc.gov/niosh/programs/oilgas/burden.html.
[276] U.S. Bureau of Labor Statistics, "Fatal Occupational Injuries in Private Sector Mining, Quarrying, and Oil and Gas Extraction Activities," U.S. Bureau of Labor Statistics, December 16, 2021, https://www.bls.gov/charts/census-of-fatal-occupational-injuries/fatal-occupational-injuries-private-sector-mining.htm.

most such fatalities and "well servicing" was by far the most common industry sub-group represented for the deaths. Consistently, the majority of deaths were transportation and contact injury related. This project is unique in counting cardiac events that begin at work, recognizing toxic exposures at oil and gas sites that can induce cardiac events, as well as work conditions that can influence their outcomes.

Pipeline construction workers also suffer elevated rates of injuries and fatalities, dying on the job 3.6 times more than workers in other industries. (See footnotes 1045, 1046.)

A University of Tennessee study assessed the occupational inhalation risks from the hazardous and carcinogenic air pollutants emitted from various sources around fracking wells and found that chemical storage tanks presented the highest cancer risk. Exposure to storage tank fumes also poses risks of cardiac arrhythmias and cardiac arrest. A July 2023 investigation found that federal warnings against workers manually testing fluids inside well pad storage tanks (manual gauging) have been largely ignored by the industry. Cardiac arrest following manual gauging was the cause of several worker deaths between 2016-2020.[277]

Benzene has been detected in the urine of well pad workers in Colorado and Wyoming. The National Institute for Occupational Safety and Health named oil and gas extraction industry workers among those at risk for silicosis, an incurable lung disease caused by exposure to silica dust, from the silica sand that is used extensively in fracking operations. (See footnotes 1057, 1059, 1101, 1033.)

In 2020, the National Violent Death Reporting System reported that among the 20 major industry groups analyzed, men in the labor sector "Mining, Quarrying, and Oil and Gas Extraction" had the highest suicide rate in 2016, at 54.2 per 100,000 workers. (See footnote 1030.)

A 2020 study showed that retired oil and gas workers had the highest prevalence of self-reported poor health of all industry categories of retirees. (See footnote 1022.)

Independent economic analyses show that the promise of job creation, especially in the Marcellus Shale region of Appalachia, was greatly exaggerated, with many fracking-related jobs going to out-of-area workers. (See footnote 2259.) During the height of the fracking boom, from 2008-2019, the most intensely drilled counties in Appalachia typically experienced both net job loss and population loss. (See footnote 2270.) Throughout all shale plays, oil and gas jobs are being increasingly lost to automation, and job losses accelerated with the contraction of the industry in 2019 and 2020. In the steepest rate of job loss in the industry's history, oil and gas eliminated 107,000 U.S. jobs between March and August 2020 alone. The result has been mass lay-offs and high unemployment among fracking crews and associated workers who often suffer occupational exposures to harmful substances and lack health insurance. By 2023, gas production in Appalachian shale basins had leveled off and may have already peaked. As a larger share of output comes from existing wells, fewer workers are needed. The number of jobs in Appalachia's principal shale gas-producing counties is continuing to decline, as are population

[277] Sara Sneath, "Fossil Fuel Workers Are Dying Inhaling Gases – despite US Warnings to Big Oil," *The Guardian*, July 13, 2023, https://www.theguardian.com/us-news/2023/jul/13/fossil-fuel-deaths-inhaling-gas.

and income. Since 2008, these counties have done worse economically than the region as a whole.[278]

8) Fracking and the injection of fracking waste cause earthquakes.

Both the practice of fracking and the injection of fracking wastewater into underground disposal wells are known triggers of earthquake swarms in multiple locations, as demonstrated by several major studies, using different methods. Newer research in Canada, Oklahoma, Kansas, Ohio, Texas, the United Kingdom, and China links the practice of fracking itself to earthquakes, including some that take place many miles from well sites and many years later, suggesting that seismic risks have been previously underestimated with much larger areas at risk and for longer periods of time.[279, 280] In 2019, the UK government halted fracking operations indefinitely after a report found that fracking-related earthquakes in Lancashire were neither predictable nor manageable with existing technology. (See footnote 1316.) In 2023, a research team in Kansas confirmed that fracking caused slipping of underground faults and, through this mechanism, triggered seismic tremors.[281, 282]

In Oklahoma, Texas, Louisiana, and New Mexico, the number of earthquakes linked to fracking wastewater injection more than tripled between 2017 and 2020. Current trends in this region show increasing frequency of fracking-related earthquakes as well as increasing strength. In 2021, according to state data analyzed by the *Texas Tribune*, Texas experienced more than 200 earthquakes of 3.0-magnitude or higher—more than double the number in 2020—with most of these quakes taking place in the West Texas Permian Basin as a consequence of fracking wastewater injection.[283] A 2021 study led by the U.S. Geological Survey determined that the proliferation of seismic activity near the Permian Basin city of Pecos since 2000 is likely caused by fracking wastewater disposal practices.[284] In addition to increased frequency of earthquakes, the Permian Basin is experiencing a spike in surface deformations—including the appearance of sinkholes, subsidence, and uplifts—as a direct consequence of drilling and fracking activities.[285]

A 2017 study of the Fort Worth Basin showed that a swarm of small earthquakes in northern Texas was originating in long-inactive fault lines in deep formations where fracking wastewater

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[278] Sean O'Leary, "Frackalachia Update: Peak Natural Gas and the Economic Implications for Appalachia" (Ohio River Valley Institute, August 22, 2023), https://ohiorivervalleyinstitute.org/frackalachia-update-peak-natural-gas-and-the-economic-implications-for-appalachia/.
[279] Pathikrit Bhattacharya and Robert C. Viesca, "Fluid-Induced Aseismic Fault Slip Outpaces Pore-Fluid Migration," *Science* 364, no. 6439 (2019): 464–68, https://doi.org/10.1126/science.aaw7354.
[280] Gillian Foulger, "Fracking Can Cause Earthquakes," *Cosmos*, May 13, 2019, https://cosmosmagazine.com/geoscience/fracking-can-cause-earthquakes-a-long-way-from-its-site.
[281] Shankho Niyogi et al., "Tremor Signals during Fluid Injection Are Generated by Fault Slip," *Science* 381, no. 6657 (August 4, 2023): 553–58, https://doi.org/10.1126/science.adh1331.
[282] Vidya Nagalwade, "New Research Solves the Mystery of 'Earthquakes' or 'Tremors' Cause," *Tech Explorist*, August 10, 2023, https://www.techexplorist.com/new-research-solves-mystery-earthquakes-tremors-cause/66545/.
[283] Erin Douglas, "Earthquakes in Texas Doubled in 2021. Scientists Cite Years of Oil Companies Injecting Sludgy Water Underground.," *Texas Tribune*, February 8, 2022, https://www.texastribune.org/2022/02/08/west-texas-earthquakes-fracking/.
[284] Robert J. Skoumal and Daniel T. Trugman, "The Proliferation of Induced Seismicity in the Permian Basin, Texas," *Journal of Geophysical Research: Solid Earth* 126, no. 6 (2021), https://doi.org/10.1029/2021JB021921.
[285] Vamshi Karanam and Zhong Lu, "Hydrocarbon Production Induced Land Deformation over Permian Basin; Analysis Using Persistent Scatterer Interferometry and Numerical Modeling," *International Journal of Applied Earth Observation and Geoinformation* 122 (August 2023): 103424, https://doi.org/10.1016/j.jag.2023.103424.

was being injected. Human activity is the only plausible explanation. (See footnotes 1354, 1355.) Another study using satellite-based radar imagery provided proof that the migration of fracking wastewater into faults increased pressures in ways that triggered a 4.8-magnitude earthquake in east Texas in 2012, while a third study documented the rupture of a fault plane that set off a 4.9-magnitude earthquake in Kansas in 2014 immediately following a rapid increase in fracking wastewater injection nearby. (See footnotes 1378, 1379.)

The number of earthquakes of magnitude 3.0 or higher skyrocketed in Oklahoma starting with the advent of the fracking boom—with fewer than two per year before 2009 and more than 900 in 2015. The 5.8 earthquake that struck near Pawnee on September 3, 2016 was the strongest in Oklahoma's history and prompted an order from state regulators to shut down 67 wastewater disposal wells in the area. (See footnotes 1376, 1377.) In October 2016, the EPA recommended a moratorium on the underground injection of fracking wastewater in certain earthquake-prone parts of Oklahoma because regulations had not solved the problem. (See footnote 1374.) Earthquake frequency began to decline in the state in 2017. In February 2018, after a new cluster of earthquakes, the state further restricted fracking activities.[286]

There is no evidence that fracking-induced earthquakes can be prevented solely by limiting the rate or volume of injected fluid. A 2018 analysis of shale basins across the United States found that shallower disposal wells can help lower the risk of earthquakes. However, injection of fracking waste into shallow formations increases the risk of groundwater contamination. (See footnote 1338.)

In China's Sichuan Province, a series of earthquakes have been linked to fracking, including one in December 2018 with a magnitude of 5.7, the largest fracking-induced earthquake to date. The likely cause was reactivation of unmapped faults by underground fluid pressure.[287] In February 2019, three additional earthquakes, all with a magnitude of over four, struck Sichuan Basin, killing two people, injuring 13, and damaging 20,000 homes. The government temporarily suspended fracking operations in the area.[288]

9) Fracking waste disposal is a problem without a solution.

Fracking generates prodigious amounts of waste that comes in two basic forms: solid waste left over from drilling—so-called drill cuttings—and liquid wastewater generated after a well is fracked. As fracking operations with horizontal drilling have evolved toward ever-longer lateral wellbores, the volumes of both solid drill cuttings and fracking wastewater have increased markedly, although no national inventories are kept and not all states collect and maintain data

[286] David Wethe, "Oklahoma Toughens Oil Fracking Rules after Shale Earthquakes," Bloomberg, February 28, 2018, https://www.bloomberg.com/news/articles/2018-02-27/oklahoma-toughens-oil-fracking-rules-as-shale-earthquakes-climb.
[287] Xinglin Lei, Zhiwei Wang, and Jinrong Su, "The December 2018 ML 5.7 and January 2019 ML 5.3 Earthquakes in South Sichuan Basin Induced by Shale Gas Hydraulic Fracturing," *Seismological Research Letters* 90, no. 3 (2019): 1099–1110, https://doi.org/10.1785/0220190029.
[288] Steven Lee Myers, "China Experiences a Fracking Boom, and All the Problems That Go with It," *The New York Times*, March 8, 2019, sec. Asia Pacific, https://www.nytimes.com/2019/03/08/world/asia/china-shale-gas-fracking.html.

on volumes of waste generated within their borders. In 1980, oil and gas waste received a Congressional exemption from the Resource Conservation and Recovery Act, the flagship federal law that regulates the disposal of hazardous waste. Hence, fracking waste is not required to be handled as hazardous although much of it highly toxic and radioactive.[289]

Drill cuttings, which largely consist of gooey, pulverized rock fragments removed from the wellbore by augurs during drilling operations, often contain highly toxic metals and naturally occurring radioactive materials such as radium, lead, uranium, thorium, and polonium isotopes. Depending on state laws, drill cuttings may be buried on site, spread on soil, or dumped in municipal landfills where their contaminants can enter the leachate created when rainwater percolates through the waste piles. The EPA has estimated that 7.5 million tons of drilling cuttings are generated each year from oil and gas operations.[290]

In Pennsylvania alone, drilling and fracking operations sent 244,000 tons of drill cuttings to landfills in 2020. A 2019 study found levels of radium in Pennsylvania drill cuttings that would exceed regulatory limits for disposal in landfills if drilling cuttings were not exempt from federal regulations governing hazardous waste. In the same year, a Fayette County water treatment plant sued after finding high levels of oil and gas contaminants in the leachate sent to it from a nearby landfill. In July 2021, the Pennsylvania Department of Environmental Protection announced it will require all landfills that take solid fracking waste to test their leachate for radioactive materials.[291] Drill cuttings from Pennsylvania fracking operations are also sent out of state for disposal, including to Ohio. (See footnote 961.)

The liquid waste that flows out a well immediately after it is fracked is called **flowback fluid**; the wastewater that continues to rise to the surface after the well is attached to a pipeline is called **produced water**. This shift in nomenclature indicates when in the extraction process the wastewater is generated and does not represent a substantive chemical difference, although flowback waste does tend to contain a higher concentration of the chemical additives used in fracking fluid, and produced water contains proportionately more brine and naturally occurring toxicants, such arsenic or barium and volatile compounds such as hydrogen sulfide and benzene. The chemicals used as ingredients in fracking fluid generally decrease over time in produced water but can persist for more than eight months after a well is put into production.[292, 293] A 2021

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[289] United States Code, "Title 42 - The Public Health and Welfare, Chapter 82 - Solid Waste Disposal, Subchapter III - Hazard Waste Management, Sec. 6921 - Identification and Listing of Hazardous Waste" (U.S. Government Publishing Office, 2010), 42, https://www.govinfo.gov/content/pkg/USCODE-2010-title42/html/USCODE-2010-title42-chap82-subchapIII-sec6921.htm.

[290] U. S. Environmental Protection Agency, Office of Land and Emergency Management, and Office of Resource Conservation and Recovery, "Management of Exploration, Development and Production Wastes: Factors Informing a Decision on the Need for Regulatory Action," April 2019, https://www.epa.gov/sites/default/files/2019-04/documents/management_of_exploration_development_and_production_wastes_4-23-19.pdf.

[291] Reid Frazier, "DEP to Require Landfills to Test for Radioactivity from Fracking Waste," State Impact Pennsylvania, July 26, 2021, https://stateimpact.npr.org/pennsylvania/2021/07/26/dep-to-require-landfills-to-test-for-radioactivity-from-fracking-waste/.

[292] Maryam A. Cluff et al., "Temporal Changes in Microbial Ecology and Geochemistry in Produced Water from Hydraulically Fractured Marcellus Shale Gas Wells," *Environmental Science & Technology* 48, no. 11 (2014): 6508–17, https://doi.org/10.1021/es501173p.

[293] Tanya J. Gallegos et al., "Insights on Geochemical, Isotopic, and Volumetric Compositions of Produced Water from Hydraulically Fractured Williston Basin Oil Wells," *Environmental Science & Technology* 55, no. 14 (2021): 10025–34, https://doi.org/10.1021/acs.est.0c06789.

study of fracking wastewater from the Utica and Marcellus shale basins found that flowback fluid from newly fractured wells was the most highly toxic. (See footnote 660.) An estimated 21.2 billion barrels of briny wastewater are generated each year from one million active oil and gas wells in the United States. (See footnotes 686-688.)

A 2022 Texas study documented the presence of many toxic and cancer-causing contaminants in fracking wastewater—including volatile organic compounds, hazardous heavy metals, and radioactive substances—at levels capable of causing health harms. Some of these hazardous contaminants represent chemical additives used in the fracking fluid itself, while others are contaminants mobilized from the geological fracture zone. (See footnote 648.)

Like drill cuttings, fracking wastewater is often radioactive and can contain a variety of radioactive substances—including radium, thorium, and uranium—particularly in the Marcellus Shale region where some water samples show Radium-226 levels at 3,600 times the EPA's safe drinking water standard. A two-part study in the Marcellus Shale region showed that extreme salinity, as well as the chemical composition of fracking fluid, interacts with the shale during the fracking process in ways that mobilize radium and make fracking wastewater radioactive. (See footnotes 979, 980.)

There is no known solution for the problem of fracking wastewater. It cannot be filtered or otherwise remediated to create clean, drinkable water, nor is there any safe method of disposal. Treating and discharging to rivers and streams is associated with elevated bromide and chloride levels downstream, as well as with the formation of cancer-causing disinfection byproducts. High levels of radium have been found in sediments downstream of sewage treatment plants in western Pennsylvania that had been used years earlier for fracking waste disposal. (See footnotes 744, 745.) Chemical analysis of produced water samples from the Permian Basin show the presence of volatile organic compounds, PFAS, and radionuclides. Nevertheless, Texas regulators are currently moving forward with plans to issue permits for dumping wastewater from both fracking and conventional wells into streams and rivers from which cattle drink.[294] (See footnote 647.)

Recycling fracking wastewater for use in new fracking operations is an expensive, limited option that increases radionuclide levels of subsequent wastewater, raises health risks for workers, incentivizes further fracking activity, and raises questions about the ultimate disposal of production wastewater from existing wells after the demand for fracking new wells ends. (See "Radioactive releases.") Disposal of liquid fracking waste into porous underground rock formations via injection wells is considered a best practice but is also a proven cause of earthquakes. (See "Earthquakes and seismic activity.") Further, many injection wells are now reaching capacity and cannot continue accepting more waste.

Transporting fracking waste to injection wells creates additional dangers. An increasing fraction of the wastewater created from fracking operations in western Pennsylvania is hauled to Ohio for disposal, both because the geology is more favorable for injection wells and because Ohio's rules governing the handling of oil and gas waste are lax and largely unenforced, leaving the disposal

[294] Martha Pskowski, "Texas' Environmental Agency Enables Companies to Increase Oilfield Wastewater Disposal in Rivers," *The Texas Tribune*, August 7, 2023, https://www.texastribune.org/2023/08/17/texas-oilfield-wastewater-rivers-tceq-fracking/.

of radioactive waste from fracking operations, in effect, entirely unregulated.[295, 296] Indeed, the state agency charged with regulating injection wells is prohibited by law from enacting penalties.[297]

Pressure is mounting to expand opportunities for the conversion of fracking waste, both solid and liquid, into ingredients for commercial products, a practice called beneficial re-use. Driving this discussion is the intractable problem of earthquakes when produced water is injected as liquid waste into deep geological formations and the declining storage capacities in shallower formations where groundwater contamination is a bigger risk. At last count, 11 states had approved various beneficial uses for drill cuttings (concrete, road base, grading). Thirteen U.S. states allow oil and gas wastewater to be used as a dust suppressant on unpaved roads. However, the presence of toxic heavy metals and radioactive radium accumulate with repetitive treatments and have the potential to become airborne. Further, a 2021 study found that the high levels of sodium render oil and gas wastewater ineffective in actually suppressing dust compared with other commercially available products.[298] However, there is almost no data collected on the frequency of different uses or the volumes involved. (See footnote 961.)

In western states suffering from water shortages and prolonged drought, the fracking industry seeks to expand the reuse of fracking wastewater for irrigation and livestock watering. At least ten known or suspected chemical carcinogens have been identified in wastewater reused for irrigation and livestock watering in California, and a 2020 study found elevated levels of sodium and boron in California soils irrigated with wastewater. Agricultural uses of wastewater raise questions about food crop contamination. Soil degradation, lower crop yields, and impaired microbial diversity were seen in land irrigated with oil and gas wastewater. Studies and case reports from across the country have highlighted instances of deaths, neurological disorders, aborted pregnancies, and stillbirths in farm animals that have come into contact with fracking wastewater. (See “Threats to agriculture, soil quality, and forests”).

10) Fracking infrastructure poses exposure risks to those living nearby.

Drilling and fracking activities are relatively short-term operations, but **compressor stations** are semi-permanent facilities that pollute the air 24 hours a day as long as gas is flowing through pipelines. Day-to-day emissions from compressor stations are subject to highly episodic variations due to pressure changes and maintenance-related deliberate releases and can create periods of potentially extreme exposures. Compressor stations generally have shorter emissions stacks than other polluting facilities such as power plants, which means their harmful emissions

[295] Talia Wiener, “Under ‘Chief’s Orders’ Ohio Operates a Radioactive Industry Off the Record” (Public Herald, July 2021), https://publicherald.org/under-chiefs-orders-ohio-operates-a-radioactive-industry-off-the-record/.
[296] Lee Ann L. Hill et al., “Temporal and Spatial Trends of Conventional and Unconventional Oil and Gas Waste Management in Pennsylvania, 1991–2017,” *Science of The Total Environment* 674 (2019): 623–36, https://doi.org/10.1016/j.scitotenv.2019.03.475.
[297] Nick Cunningham, “Alleging ‘Failures’ to Protect Drinking Water, Coalition Urges EPA to Take Over Ohio Fracking Waste Wells,” *DeSmog*, November 18, 2022, https://www.desmog.com/2022/11/18/epa-petition-ohio-fracking-waste-injection-well-primacy/.
[298] Audrey M. Stallworth et al., “Efficacy of Oil and Gas Produced Water as a Dust Suppressant,” *Science of the Total Environment*, https://doi.org/10.1016/j.scitotenv.2021.149347, 799 (2021).

are more concentrated at ground level than if released from a greater height. A 2019 study of air emissions from 74 compressor stations in New York State found 39 chemicals known to be human carcinogens and documented large releases of greenhouse gases. (See footnote 1983.)

Because of their high pressures, compressor station explosions can have catastrophic consequences. In January 2019, a compressor station in rural Michigan malfunctioned during a period of extreme cold and released a large amount of methane gas that ignited and exploded.

Safety-related risks at Enbridge natural gas compressor station in **Weymouth, Massachusetts** includes injuries that could extend for thousands of feet into densely populated residential neighborhoods in the case of a catastrophic explosion.[299, 300] Since becoming operational in January 2021, the Weymouth compressor station has suffered multiple accidents that sent plumes gas and volatile organic compounds into the community's airshed. In addition, its routine maintenance requires the periodic venting of methane into the atmosphere.[301, 302] In 2022, the Federal Energy Regulatory Commission (FERC) re-examined its decision to grant the permit and issued a statement saying that it "likely erred" in siting the compressor station in a "heavily populated area with two environmental justice communities and a higher-than-normal level of cancer and asthma due to heavy industrial activity." However, the Commission stopped short of revoking its approval.[303] Area residents are pressing forward with their opposition in the courts.

The Weymouth compressor station is a key component of the Enbridge Atlantic Bridge pipeline project intended to ferry fracked gas beneath the Boston Harbor and north into Canada. Investigations by journalists Itai Vardi and Mike Stanton explicated a tangle of industry conflicts of interest during the permitting process, as well as sleight-of-hand revisions in early drafts of the health impact assessment that deleted from the final report evidence documenting serious risks to nearby residents.[304, 305]

Pipelines themselves can freeze, corrode, break, and leak. Low-pressure flow lines alone have been responsible for more than 7,000 spills and leaks since 2009. (See footnote 2018.)

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[299] Anna Baker et al., "Flammable, High-Pressure Industry in a Populated Coastal Flood Zone? Public Safety and Emergency Response Aspects of a Proposed Methane Gas Compressor in Weymouth" (Greater Boston Physicians for Social Responsibility, May 13, 2019), https://www.psr.org/wp-content/uploads/2019/05/compressor-public-safety-report.pdf.

[300] Regina LaRocque, Brita Lundberg, and Zoe Petropoulos, "A Comprehensive Assessment of the Potential Human Health Impacts of a Proposed 'natural' Gas Compressor Station in Weymouth, Massachusetts" (Greater Boston Physicians for Social Responsibility, September 24, 2019), https://gbpsr.org/wp-content/uploads/sites/11/2019/09/gbpsr-report-09-24-19.pdf.

[301] Joseph Winters, "The Weymouth Compressor Station," *Harvard Political Review*, May 24, 2021, https://harvardpolitics.com/weymouth-compressor-station/.

[302] Jessica Trufant, "Natural Gas Release Planned near Weymouth Compressor Station This Week," *The Patriot Ledger*, February 21, 2023, https://www.patriotledger.com/story/news/2023/02/21/natural-gas-release-planned-for-fore-river-compressor-station-weymouth-quincy-embridge/69912851007/.

[303] Jessica Trufant, "Feds: Regulators 'Should Never Have Approved' Weymouth Compressor, Too Late to Shut It Down," *The Patriot Ledger*, January 20, 2022, https://www.patriotledger.com/story/news/2022/01/20/federal-regulators-say-they-cant-shut-down-compressor-station/6593139001/.

[304] Itai Vardi, "Revealed: Contractors Hired by FERC to Review a New Spectra Energy Pipeline Work for Spectra on a Related Project," DeSmog, May 26, 2016, https://www.desmogblog.com/2016/05/26/revealed-contractors-hired-ferc-review-new-spectra-energy-pipeline-work-spectra-related-project.

[305] Mike Stanton, "In Weymouth, a Brute Lesson in Power Politics," *Boston Globe*, December 12, 2020, https://www.bostonglobe.com/2020/12/12/metro/was-it-ever-fair-fight/.

Distribution lines that deliver gas into homes and offices are a significant source of leaking methane and contribute to the death of urban trees. (See footnote 1973.)

Significant pipeline accidents happen roughly 300 times each year in the United States and, between 1998 and 2017, killed 299 people and injured 1,190 others, according to the PHMSA. Extreme weather patterns caused by climate change are making pipeline accidents more likely. Landslides, sinking and caving of land, and other types of land movement have been linked to at least six ruptures and explosions of gas pipelines built in the steeply sloped Appalachian Mountains. In May 2019, PHMSA sent a warning to pipeline operators about increased risks of leaks and explosions caused by more frequent flooding, sinkholes, and severe rainfall patterns in the eastern United States.[306] In September 2018, heavy rains and landslides triggered the explosion of the **Revolution Pipeline** in Beaver County, Pennsylvania, destroying a house.[307] In February 2022, Energy Transfer was charged with nine environmental crimes related to that explosion after a grand jury investigation found it had failed to oversee construction and prevent erosion.[308] In August 2020, a sinkhole formed during the construction of the **Mariner East Pipeline** in Chester County, Pennsylvania, and 8,000 gallons of drilling fluid bubbled to the surface, contaminating a lake in a state park.[309] Subsidence and the development of sinkholes have plagued the Mariner East Pipeline since construction began and continues to delay its completion. The Mariner East would transport natural gas liquids from the Marcellus Shale fields in western Pennsylvania to an export terminal on the Delaware River near Philadelphia.

Gas-fired power plants are major emitters of carbon monoxide and nitrogen oxides, which contribute to smog. In Virginia, greenhouse gas emissions increased after the state largely retired its fleet of coal-burning power plants and replaced them with gas-fired facilities. (See footnote 2216.)

In the Upper Midwest, Wisconsin residents living near **silica sand mining operations** that service the fracking industry reported dust exposure and respiratory problems. Silica dust is a known cause of silicosis and lung cancer. West Texas is also experiencing a fracking sand boom, which is depleting groundwater supplies in an arid region.[310] (See also footnote 7.)

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[306] Pipeline Hazardous Materials Safety Administration, "Pipeline Safety: Potential for Damage to Pipeline Facilities Caused by Earth Movement and Other Geological Hazards" (National Archives and Records Administration, May 2, 2019), https://www.federalregister.gov/documents/2019/05/02/2019-08984/pipeline-safety-potential-for-damage-to-pipeline-facilities-caused-by-earth-movement-and-other.

[307] Susan Phillips, "Federal Pipeline Safety Regulators Issue Warning on Floods and Subsidence," State Impact Pennsylvania, May 21, 2019, https://stateimpact.npr.org/pennsylvania/2019/05/21/federal-pipeline-safety-regulators-issue-warning-on-floods-and-subsidence/.

[308] Reid Frazier, "Energy Transfer Facing Nine Counts of Environmental Crimes for 2018 Pipeline Blast," State Impact Pennsylvania, February 3, 2022, https://stateimpact.npr.org/pennsylvania/2022/02/03/energy-transfer-facing-nine-counts-of-environmental-crimes-for-2018-pipeline-blast/.

[309] Andrew Maykuth, "Sunoco Wants to Block Order to Reroute Mariner East Pipeline Away from Chester's Marsh Creek Lake," *The Philadelphia Inquirer*, October 26, 2020, sec. Business, https://www.inquirer.com/business/mariner-east-pipeline-sunoco-energy-transfer-pennsylvania-marsh-creek-leak-chester-county-20201026.html.

[310] Robert Mace and Chelsea Jones, "Frac Sand Facilities and Their Potential Effects on the Groundwater Resources of the Monahans-Mescalero Sand Ecosystem, Permian Basin, Texas," *Texas Water Journal* 14, no. 1 (June 26, 2023): 62–80, https://doi.org/10.21423/twj.v14i1.7132.

Fracking infrastructure in the United States also includes 400 **underground gas storage facilities** in 31 states, with aging equipment and scant federal oversight. A four-month leak at the nation's fifth-largest facility, **Aliso Canyon** in southern California, resulted in exposures of a large suburban population to an uncontrollable array of chemicals. With a release of nearly 100,000 metric tons of methane between October 2015 and February 2016, it became the worst methane leak in U.S. history. (See footnote 2108.) It exposed residents in the region to benzene spikes, high ongoing odorant releases, hydrogen sulfide at levels far above average urban levels, and many other contaminants of concern. More than 8,300 households were evacuated and relocated, with residents reporting multiple symptoms, including headaches, nosebleeds, eye irritation, and nausea. As part of a 2019 agreement with city, county and state authorities, SoCalGas must pay for the health study.[311] Many have criticized the long wait for the study, its reliance on flawed monitoring, and possible exclusion of clinical evaluation. (See footnote 2067.) In November 2022, after much delay, the Los Angeles County Health Department awarded a $21 million grant to UCLA for the Aliso Canyon Disaster Health Research Study. Among other things, the five-year investigation will include a complex environmental analysis and modeling of the exposure residents faced at the time of the leak and after.[312]

In May 2019, state investigators announced that the cause of the massive leak at Aliso Canyon was the rupture of a well casing triggered by microbial corrosion within a well that had been originally drilled in 1954 and, over the years, had come in contact with groundwater.[313] The report also faulted the operator, SoCalGas, for failure to monitor and investigate more than 60 previous leaks at the gas storage complex.[314] In November 2020, over intense public opposition, the California Public Utilities Commission voted unanimously to allow the Aliso Canyon facility to maintain its current storage capacity until a study could determine the feasibility of shutting it down.[315] In November 2021, The California Public Utilities Commission voted to increase storage at the facility, although the Commissioner said the increase would not be permanent and "in no way diminishes the ability to decommission Aliso."[316] (See also footnote 2113.) The shutdown feasibility study has not been released. A state senator has introduced a bill that would,

[311] Hayley Smith, "L.A. County Calls for Independent Health Study of Massive Natural Gas Leak in Aliso Canyon," *Los Angeles Times*, January 20, 2022, https://www.latimes.com/california/story/2022-01-20/l-a-county-calls-for-independent-health-study-of-massive-natural-gas-leak-in-aliso-canyon.
[312] UCLA Health, "Aliso Canyon Gas Blowout: UCLA to Study Health Impacts of One of the Worst Environmental Disasters in Southern California," *UCLA Health*, November 9, 2022, https://www.uclahealth.org/news/aliso-canyon-gas-blowout-ucla-to-study-health-impacts-of-one-of-the-worst-environmental-disasters-in-southern-california.
[313] Blade Energy Partners, "Root Cause Analysis of the Uncontrolled Hydrocarbon Release from Aliso Canyon" (California Public Utilities Commission, May 16, 2019), https://www.californiageo.org/wp-content/uploads/Exec-Sum-on-Aliso-by-Blade-5-16-19.pdf.
[314] Mihir Zaveri, "Corroded Well Lining Caused Aliso Canyon Gas Leak That Displaced Thousands, Report Says," *The New York Times*, May 17, 2019, https://www.nytimes.com/2019/05/17/business/porter-ranch-gas-leak.html.
[315] Linh Tat, "Pleas Spurned to Limit Storage at Aliso Canyon, Site of Massive Gas Leak 5 Years Ago," *Los Angeles Daily News*, November 19, 2020, sec. News, from https://www.dailynews.com/2020/11/19/socalgas-aliso-canyon-gas-storage-facility-eludes-limits-on-capacity/.
[316] Gregory Yee, "Utilities Commission Approves Gas Storage Plan at Aliso Canyon over Residents' Objections," *Los Angeles Times*, November 5, 2021, https://www.latimes.com/california/story/2021-11-05/utilities-commission-approves-gas-storage-plan-at-aliso-canyon-site-over-residents-objections.

no later than an unspecified date in 2027, [close] all natural gas operations at the Aliso Canyon natural gas storage facility."[317]

In a 2018 analysis of the safety risks of all 14 facilities in California that store gas in depleted oil fields, the California Council of Science and Technology found that gas companies do not disclose the chemicals they are pumping underground nor do state regulators possess the necessary information to assess risks. Further, many wells servicing the storage fields are 60 to 90 years old with no regulatory limit to the age of a well. (See footnote 2101.) After the price and demand collapse in mid-2020, producers sought and received special permission to store growing inventories of oil and gas in underground salt caverns in Texas for up to five years over concerns about possible threats to the nine aquifers underlying the state. (See footnote 2074.)

LNG facilities create acute security, public safety, and climate threats, as well as massive coastal habitat destruction. LNG is purified methane in the form of a bubbling, super-cold liquid. It is created through the capital-intensive, energy-intensive process of cryogenics and relies on evaporative cooling, via methane venting, to keep the liquid fuel chilled during transport. LNG is explosive and possesses the ability to flash-freeze human flesh. Its greenhouse gas emissions are 30 percent higher than conventional natural gas due not only to its need for venting and refrigeration but also because flaring is used to control pressure when converting the liquid back into a gas. The need to strip volatile impurities such as benzene from the gas prior to chilling it also makes LNG liquefaction plants a source of toxic air pollutants. (See footnotes 2142-2199.)

Cheniere Energy's **Sabine Pass terminal** in Louisiana became the subject of a federal investigation in 2019 after a steel storage tank cracked and escaping LNG quickly vaporized into a flammable cloud. Another tank was found to be leaking gas from multiple places. PHMSA ordered both tanks shut down.[318] In June 2022, the explosion and fire at the **Freeport LNG terminal** in Texas shut down one-fifth of the nation's LNG export capacity for several months and was the latest in a string of accidents at that facility.[319]

In Coos Bay, Oregon, the proposed **Jordan Cove LNG export terminal** and its associated pipeline from Canada would have imperiled 20 different threatened and endangered species and crossed 300 bodies of water. In 2021, the developer, unable to secure state permits to operate, put the project on indefinite hold and asked FERC to cancel authorizations for both the export terminal and the Pacific Connector pipeline.[320]

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[317] Henry Stern, "SB 1486 Natural Gas: Aliso Canyon Natural Gas Storage Facility: Reliability.," Openstates, February 18, 2022, https://openstates.org/ca/bills/20212022/SB1486/.
[318] Jenny Mandel and Jie Jenny Zou, "Leaks Threaten Safety—and Success—of America's Top Natural Gas Exporter," The Center for Public Integrity, May 30, 2019, https://publicintegrity.org/environment/leaks-threaten-safety-and-success-of-americas-top-natural-gas-exporter/.
[319] Mike Soraghan, Mike Lee, and Carlos Anchondo, "LNG Plant Had History of Safety Issues before Explosion," *E&E EnergyWire*, June 15, 2022, https://www.eenews.net/articles/lng-plant-had-history-of-safety-issues-before-explosion/.
[320] Niina H. Farah, Miranda Willson, and Carlos Anchondo, "Jordan Cove Project Dies. What It Means for FERC, Gas," *E&E News*, December 2, 2021, https://www.eenews.net/articles/jordan-cove-project-dies-what-it-means-for-ferc-gas/.

11) Drilling and fracking activities release radioactivity.

Naturally occurring radioactive substances often co-occur with oil and gas inside the deep shale layers that are targeted for fracking. These substances are brought to the surface in the rocky material removed during drilling (drill cuttings) and in fracking wastewater. A July 2023 study found elevated levels of radium in sediments downstream from landfills in Pennsylvania, Ohio, and New York State that had accepted liquid fracking waste.[321] A 2023 investigation by journalist Justin Nobel documented "concerning levels" of radium in the tanks, waste pond, and soil surrounding a fracking waste treatment plant in Fairmont, West Virginia.[322] Fracking itself can open pathways for the migration of radioactive materials, which can be released as airborne particles from the wellhead itself during operations. Radionuclides can build up in pipes, equipment, and trucks. Exposure to increased radiation levels from fracking materials is a risk for both workers and residents.

Levels of radon—a radioactive, carcinogenic gas—inside Pennsylvania homes have risen since the advent of the fracking boom, and buildings in heavily drilled areas have significantly higher radon readings than areas without well pads, a difference that did not exist before 2004. Similar patterns have been documented in Ohio. The results of a 2021 Pennsylvania study, however, were less clear. (See footnotes 958, 976, 993.)

A 2018 simulation study of radium-226 in fracking wastewater from North Dakota's Bakken Shale found potential risk to human health from fracking wastewater spills into surface water. (See footnote 982.)

Potential radioactive exposures are particularly concerning for drivers of brine trucks, as was documented in a 2020 investigative report on radium in liquid fracking waste. In at least 13 states where it is legal, oil and gas waste that may be radioactive is purposely spread on roadways as a de-icer in the winter and/or as a dust-control agent in the summer. (See footnote 971.)

In 2020, a Harvard team documented the presence of airborne radioactivity downwind from fracking sites at levels sufficient to raise health risks for nearby residents. Using data collected from 157 radiation-monitoring stations built across the nation during the Cold War, the researchers showed a seven percent increase in radioactive pollution in communities located 12 to 31 miles downwind from operational fracking sites as compared to background levels. The closer communities were located to the wells, the higher the radioactivity in airborne particles. In the Fort Worth, Texas area, where more than 600 fracking wells are located upwind from the city, the team estimated a 40 percent increase in radiation levels. The radioactive elements carried by the ultrafine particles, including polonium, represent the radioactive decay products of uranium isotopes that are liberated from the shale during fracking operations. (See footnote 962.)

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[321] Lauren M. Badertscher et al., "Elevated Sediment Radionuclide Concentrations Downstream of Facilities Treating Leachate from Landfills Accepting Oil and Gas Waste," *Ecological Indicators* 154 (October 2023): 110616, https://doi.org/10.1016/j.ecolind.2023.110616.

[322] Justin Nobel, "Inside West Virginia's Chernobyl," *Truthdig*, September 18, 2023, https://www.truthdig.com/articles/inside-west-virginias-chernobyl/.

12) Drilling and fracking activities harm wildlife.

Animals serve as sentinels for chemical exposures that may also affect human residents who share their environment. In addition, animals perform ecosystem services essential to human existence, as confirmed by a landmark United Nations report in May 2019.[323] For both reasons, harm to wildlife by fracking operations has consequences for public health.

Fracking impacts on wildlife are profound, diverse and widespread.

Wildlife can be killed outright by gas flares and chemical pollution. Birds and other wildlife have been poisoned by fracking wastewater held in open pits, while spills and discharges of fracking waste have precipitated mass die-offs of fish, as documented in Ohio, Kentucky, and Pennsylvania. (See footnotes 859, 884.) Freshwater mussels, which are endangered throughout North America, accumulate contaminants, including strontium, when fracking wastewater is discharged through sewage treatment plants. (See footnote 707.) Chemicals in fracking waste are toxic to, or otherwise disrupt development in, many species of fish and amphibians. (See footnotes 699, 779.) In remote locations in Pennsylvania, streams once classified as high-quality brook trout habitat had no fish at all after the arrival of drilling and fracking operations. (See footnote 764.) Overall, aquatic habitats impacted by fracking activities show decreased biodiversity.

Wildlife is harmed by fracking through loss of food resources. Water fleas (*Daphnia spp.*), the basis of freshwater aquatic food chains, become unable to vertically navigate through water columns upon exposure to trace amounts of fracking fluid. (See footnote 694.) In West Virginia, populations of Louisiana waterthrush, a warbler that relies on aquatic food sources, have declined in areas of drilling and fracking. (See footnotes 700, 1629.)

Light and noise pollution from oil and gas production disrupt wildlife behavior, including in protected areas and critical habitats of endangered species, and have been linked to mass die-offs of waterfowl and declines in songbird populations in Alberta, Canada, Pennsylvania, West Virginia, eastern Ohio, and New Mexico. (See footnotes 1263, 1278.) Chronic noise from drilling and fracking operations interferes with the ability of birds to respond to acoustic cues. (See footnotes 2006, 2007.) A 2021 study found that natural gas compressor stations emit loud, low-frequency noise that travels hundreds of meters, is audible to birds, and lowers the hatching success of eastern bluebirds and tree swallows. (See footnote 1951.) Wildlife biologists in West Virginia found genetic changes in the Louisiana waterthrush that were linked to fracking activities and possible exposure to the heavy metals barium and strontium. (See footnote 1629.)

Fracking harms wildlife through climate change and habitat destruction. Oil and gas infrastructure, including compressor stations, has caused declines in grassland songbirds in Canada. Populations of forest songbirds declined markedly in response to even low levels of fracking activities in dense forested Appalachian regions. Sand mining operations in Texas are imperiling the dunes sagebrush lizard. The proposed route of the now-canceled Atlantic Coast

[323] S. Diaz et al., "Summary for Policymakers of the Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services" (IPBES Secretariat, 2019), https://ipbes.net/sites/default/files/inline/files/ipbes_global_assessment_report_summary_for_policymakers.pdf.

Pipeline would have cut through critical habitat for four endangered species.

The route of the Mountain Valley Pipeline, bisecting steep, highly erodible terrain in Virginia and West Virginia, would cross 1,108 bodies of water and 235 miles of forest, including 24 core forest areas, 892 acres of which would suffer permanent damage.[324] A 2019 study found that forest disturbances driven by drilling and fracking activities are altering the abundance of songbird populations in central Appalachia, particularly harming species whose habitats are forest interiors.[325] Well pad construction hastens the spread of invasive non-native plant species which harms wildlife habitat. (See footnotes 1638, 1642.)

According to economists, the cost of wildlife habitat fragmentation due to fracking is $3.5 to 4.45 billion per year. (See footnote 2310.)

13) The economic instabilities of fracking exacerbate public health risks.

Fracking is not a stable business. In contrast with conventional drilling, fracking operators are unable to forecast how much oil or gas can be extracted from a given shale basin based on the production of existing wells. Shale wells deplete more rapidly than conventional wells and often yield significantly less oil and gas than their operators predict to their investors. Because the production of individual shale wells falls precipitously over the course of a few years, operators must continue drilling new wells at an ever-swifter pace to maintain growth targets—even as owners are under pressure to cut costs in the face of price declines.

The result is lack of profits, dependency on Wall Street financing and low-interest loans, tax incentives, and asset sell-offs throughout the fracking industry as a whole. These unstable economic fundamentals have multiple consequences for public health and safety as cumulative impacts mount from wells both old and new. (See footnotes 2389, 2390, 2392, 2393.)

Pressures to cut costs incentivize cutbacks in safety measures and leave landscapes pock-marked by increasing numbers of abandoned wells in need of remediation and long-term monitoring. The ongoing financial crisis in the oil and gas industry, and the resulting bankruptcy waves, have allowed companies, which are typically insufficiently bonded, to walk away from inactive wells and shift decommissioning and clean-up costs to the public. (See Emerging Trend 2 above.)

In both North Dakota's Bakken Shale and western Texas' Permian Basin, cost-cutting pressures, coupled with a rush to drill new oil wells to compensate for declining rates of production from older wells, have meant that waste natural gas generated as a byproduct of oil drilling is simply

[324] Federal Energy Regulatory Commission, "Mountain Valley Project and Equitrans Expansion Project: Final Environmental Impact Statement," June 2017, https://bloximages.newyork1.vip.townnews.com/roanoke.com/content/tncms/assets/v3/editorial/b/04/b0452cda-e2b8-5925-a221-9ca818399c60/594de39d9433e.pdf.pdf.
[325] Laura Farwell et al., "Proximity to Unconventional Shale Gas Infrastructure Alters Breeding Bird Abundance and Distribution," *The Condor* 121, no. 3 (2019): 1–20.

wasted—vented or flared rather than captured—in order to speed up the rate of oil drilling.[326, 327] By April 2019, the amount of natural gas burned off via flaring in the Permian oil fields had reached a record high and exceeded the amount of gas needed to power every residence in Texas.[328, 329] According to state data compiled by the U.S. Energy Information Administration, the amount of natural gas lost to venting and flaring operations across the nation nearly doubled between 2015 (when 289,545 million cubic feet were lost) to 2019 (when 538,479 million cubic feet were lost).[330]

14) The social costs of fracking are severe.

With the arrival of drilling and fracking operations, communities have experienced steep increases in rates of crime including sex trafficking, rape, assault, drunk driving, drug abuse, and violent victimization—all of which carry public health consequences, especially for women.

Social costs include road damage, failed local businesses, loss of affordable rental housing, higher divorce rates, and strains on law enforcement and municipal services. School districts report increased stress, increased absenteeism, and lower student test scores. Economic analyses have found that drilling and fracking activities threaten property values and can diminish tax revenues for local governments. Additionally, drilling and fracking on private land pose an inherent conflict with mortgages and property insurance due to the hazardous materials used and the associated risks. (See "Inaccurate jobs claims, increased crime rates, threats to property values and mortgages, and local government burden.")

A 2019 study that monetized the external and cumulative costs of health and climate impacts of fracking in Appalachia found that, from 2004 to 2016, premature deaths caused by the industry's pollution had a cumulative economic cost of $23 billion, while climate impacts cost an additional $34 billion. Their findings showed that one year of life is lost for every three job years created by the industry. (See footnote 2281.)

[326] Catherine Ngai, "Mind the Drop: Decline Rates from Maturing Oil Wells on the Rise," Bloomberg, October 9, 2018, https://www.bloombergquint.com/business/mind-the-drop-decline-rates-from-maturing-oil-wells-on-the-rise.
[327] Mike Lee, "Gas Glut Spurs Near-Record Flaring across Shale States," *E&E News*, May 8, 2019, https://web.archive.org/web/20190508141234/https://www.eenews.net/energywire/stories/1060292021021.
[328] Jennifer Hiller, "Natural Gas Flaring Hits Record High in First Quarter in U.S. Permian Basin," Reuters, June 4, 2019, https://www.reuters.com/article/us-usa-shale-flaring/natural-gas-flaring-hits-record-high-in-first-quarter-in-us-permian-basin-idUSKCN1T5235.
[329] Kevin Crowley and Ryan Collins, "Oil Producers Are Burning Enough 'waste' Gas to Power Every Home in Texas," Bloomberg, April 10, 2019, https://www.bloomberg.com/news/articles/2019-04-10/permian-basin-is-flaring-more-gas-than-texas-residents-use-daily.
[330] U.S. Energy Information Administration, "Natural Gas Annual" (U.S. Department of Energy, September 30, 2020), https://web.archive.org/web/20201018020729/https://www.eia.gov/naturalgas/annual/pdf/nga19.pdf. Table 1, Summary Statistics for natural gas in the United States, 2015-2019, September 30, 2020, https://www.eia.gov/naturalgas/annual/pdf/nga19.pdf

15) Fracking violates principles of environmental justice and human rights.

Inequalities in opportunities to participate in environmental decision-making, as well as uneven impacts of environmental hazards along racial and socioeconomic lines, are signature issues of environmental justice. Studies consistently show that Black, Indigenous, Hispanic, rural, and low-income white communities bear the brunt of exposures to toxic waste and fossil fuel-derived air pollution.[331, 332, 333] These patterns extend to fracking and its infrastructure.[334] Across the United States, historically marginalized populations disproportionately live near active oil and gas wells.[335]

In acknowledgement, the U.S. Federal Energy Regulatory Commission announced for the first time in February 2022 that it will consider a proposed project's impact on environmental justice communities as part of its determinations.[336] As argued in a 2023 analysis, "fossil fuel racism" is a subset of environmental racism that has enabled the fossil fuel industry to externalize the costs of pollution onto communities of color.[337]

In multiple regions where fracking is practiced, well pads, pipelines, and associated infrastructure are disproportionately sited in non-white, Indigenous, or low-income communities.[338, 339] A 2019 analysis of socio-demographic characteristics of people living close to drilling and fracking operations in the states of Colorado, Oklahoma, Pennsylvania, and Texas found strong evidence that minorities, especially African Americans, disproportionately live near fracking wells.[340] A nationwide study in 2021 found that Black, Indigenous, and people of color in the United States are disproportionately exposed to flaring from drill and fracking

[331] Christopher W. Tessum et al., "Inequity in Consumption of Goods and Services Adds to Racial–Ethnic Disparities in Air Pollution Exposure," *PNAS* 116, no. 3 (2019): 6001–6, https://doi.org/10.1073/pnas.1818859116.
[332] Nikayla Jefferson and Leah C. Stokes, "Our Racist Fossil Fuel Energy System," *Boston Globe*, July 17, 2020, https://www.bostonglobe.com/2020/07/13/opinion/our-racist-fossil-fuel-energy-system/.
[333] Jill Johnston, "Chemical Exposures, Health, and Environmental Justice in Communities Living on the Fenceline of Industry," *Current Environmental Health Reports* 7 (2020): 48–57, https://doi.org/10.1007/s40572-020-00263-8.
[334] Adrianne C. Kroepsch et al., "Environmental Justice in Unconventional Oil and Natural Gas Drilling and Production: A Critical Review and Research Agenda," *Environmental Science & Technology* 53, no. 12 (2019): 6601–15, https://doi.org/10.1021/acs.est.9b00209.
[335] Jeremy Proville et al., "The Demographic Characteristics of Populations Living near Oil and Gas Wells in the USA," *Population and Environment* 44, no. 1–2 (September 2022): 1–14, https://doi.org/10.1007/s11111-022-00403-2.
[336] Federal Energy Regulatory Commission, "Certification of New Interstate Natural Gas Facilities: [Docket No. PL18-1-000]" (United States, February 18, 2022), https://www.ferc.gov/media/pl18-1-000.
[337] Timothy Q. Donaghy et al., "Fossil Fuel Racism in the United States: How Phasing out Coal, Oil, and Gas Can Protect Communities," *Energy Research & Social Science* 100 (June 2023): 103104, https://doi.org/10.1016/j.erss.2023.103104.
[338] Noel Healy, Jennie C. Stephens, and Stephanie Malin, "Embodied Energy Injustices: Unveiling and Politicizing the Transboundary Harms of Fossil Fuel Extractivism and Fossil Fuel Supply Chains," *Energy Research & Social Science* 48 (n.d.): 219–34, https://doi.org/10.1016/j.erss.2018.09.016.
[339] Emily Clough, "Environmental Justice and Fracking: A Review," *Current Opinion in Environmental Science & Health* 3 (2018): 14–18, https://doi.org/10.1016/coesh.2018.02.005.
[340] Klara Zwickl, "The Demographics of Fracking: A Spatial Analysis for Four U.S. States.," *Ecological Economics* 161 (2019): 202–15, https://doi.org/10.1016/j.ecolecon.2019.02.001.

operations.[341] A 2023 study found that gas flaring is a significant matter of energy justice in 14 different countries around the globe.[342]

In southern Texas, patterns of racially biased permitting have been documented in the heavily drilled Eagle Ford where non-white communities are targeted for both fracking waste disposal and fracking-associated flare stacks. In 2016, a public health research team showed that disposal wells for fracking wastewater were more than twice as common in areas where residents are more than 80 percent people of color than in majority-white communities.[343] Since 2007, more than 1,000 waste disposal wells have been permitted in the Eagle Ford Shale region where groundwater is the primary source of drinking water.[344] A 2020 study found that Hispanic residents living in the Eagle Ford area were exposed to significantly more fracking-associated flaring than white residents. Flares to burn off unwanted methane can operate continuously for months, releasing hazardous air pollutants as well as serving as sources of noise and light pollution.[345] Living near gas flaring operations raises the risk of preterm birth among pregnant women.[346]

Racial patterns of gas and oil development also exist in the eighteen counties in North Texas that sit atop the intensely drilled Barnett Shale. In Denton, Texas, a study found that those economically benefiting most from shale gas fracking mostly lived elsewhere, while the environmental burdens remained local and fell hardest on those who did not have a voice in mineral-leasing decisions. "Non-mineral owners are essentially excluded from the private decisions, as the mineral owners not only receive the direct monetary benefits, but also hold a great deal of state-sanctioned power to decide if and how [shale gas development] proceeds."[347] In August 2020, residents in nearby Arlington, Texas, appealed to the city's racial justice

[341] Lara J. Cushing et al., "Up in Smoke: Characterizing the Population Exposed to Flaring from Unconventional Oil and Gas Development in the Contiguous US," *Environmental Research Letters* 16 (2021), https://doi.org/10.1088/1748-9326/abd3d4.
[342] Godwin O. Aigbe, Matthew Cotton, and Lindsay C. Stringer, "Global Gas Flaring and Energy Justice: An Empirical Ethics Analysis of Stakeholder Perspectives," *Energy Research & Social Science* 99 (May 2023): 103064, https://doi.org/10.1016/j.erss.2023.103064.
[343] Jill E. Johnston, Emily Werder, and Daniel Sebastian, "Wastewater Disposal Wells, Fracking, and Environmental Injustice in Southern Texas," *American Journal of Public Health* 106, no. 3 (n.d.): 550–56, https://doi.org/10.2105/AJPH.2015.303000.
[344] Brian Bienkowski, "Fracking's Costs Fall Disproportionately on the Poor and Minorities in South Texas," Inside Climate News, February 17, 2016, https://insideclimatenews.org/news/17022016/poor-minorities-carry-burden-fracking-waste-south-texas-eagle-ford-shale/#:~:text=Fracking%E2%80%99s%20Costs%20Fall%20Disproportionately%20on%20the%20Poor%20and,Brian%20Bienkowski%2C%20Environmental%20Health%20News%20February%2017%2C%202016.
[345] Jill E. Johnston et al., "Environmental Justice Dimensions of Oil and Gas Flaring in South Texas: Disproportionate Exposure among Hispanic Communities," *Environmental Science & Technology* 54, no. 10 (n.d.): 6289–98, https://doi.org/10.1021/acs.est.0c00410.
[346] Jill E. Johnston and Lara Cushing, "The Risk of Preterm Birth Rises near Gas Flaring, Reflecting Deep-Rooted Environmental Injustices in Rural America," The Conversation, August 20, 2020, https://theconversation.com/the-risk-of-preterm-birth-rises-near-gas-flaring-reflecting-deep-rooted-environmental-injustices-in-rural-america-143413.
[347] Matthew Fry, Adam Briggle, and Jordan Kincaid, "Fracking and Environmental (in)Justice in a Texas City," *Ecological Economics* 117 (2015): 97–107, https://doi.org/10.1016/j.ecolecon.2015.06.012.

resolution to block the expansion of fracking activity near African-American and Hispanic neighborhoods.[348]

Poor communities of color are disproportionately affected by drilling activities in California. More than three-quarters of the 21,397 new oil wells drilled in California between 2011 and 2018 are located in low-income minority communities, according to state data.[349] A 2023 study found that Californians living near active oil or gas wells are disproportionately Black, Latinx, or low-income. The widest disparities were for Black Californians who were far more likely to live in neighborhoods with the most intensive oil and gas operations. Specifically, the proportion of Black residents living near active wells was 42-49 percent higher than the proportion of Black residents across the state.[350, 351]

Of Los Angeles residents living within a quarter mile of a well, more than 90 percent are people of color. In November 2015, civic groups led by youth sued the city of Los Angeles for racial discrimination based on allegations of a preferential permitting process and unequal regulatory enforcement for oil wells located in neighborhoods of color. Together, these differential practices have resulted in a higher concentration of wells with fewer environmental protections in Black and Latino communities.[352] South Coast Air Quality Management District records show that oil drilling operations in Los Angeles neighborhoods released into the air 21 million pounds of toxic chemicals between June 2013 and February 2017. These emissions included crystalline silica, hydrofluoric acid, and formaldehyde.[353] Almost one quarter of Los Angeles County's drinking water system serving more than seven million residents have supply wells located within one kilometer (0.62 miles) of an active or idle oil well. Vulnerable to chemical contamination, these drinking water wells disproportionately serve communities of color that were historically red-

[348] Kara Harris, "A Texas Oil Town Takes on Fracking as a Racial Justice Issue," Bloomberg Law, August 28, 2020, https://news.bloomberglaw.com/environment-and-energy/a-texas-oil-town-takes-on-fracking-as-a-racial-justice-issue.
[349] Center for Biological Diversity, "Analysis: Most Oil Wells Approved by Gov. Brown Are in Low-Income Areas, Communities of Color," press release, August 16, 2018, https://www.biologicaldiversity.org/news/press_releases/2018/california-oil-drilling-08-16-2018.php.
[350] David J. X. González et al., "Temporal Trends of Racial and Socioeconomic Disparities in Population Exposures to Upstream Oil and Gas Development in California," *GeoHealth* 7, no. 3 (March 2023), https://doi.org/10.1029/2022GH000690.
[351] Kara Manke, "Black, Latinx Californians Face Highest Exposure to Oil and Gas Wells," *Berkeley News*, March 23, 2023, https://news.berkeley.edu/2023/03/23/black-latinx-californians-face-highest-exposure-to-oil-and-gas-wells/.
[352] Emily Alpert Reyes, "Environmental Advocates Sue L.A., Accusing It of 'rubber Stamping' Oil Drilling Plans," *Los Angeles Times*, November 6, 2015, sec. California, http://www.latimes.com/local/lanow/la-me-ln-lawsuit-oil-drilling-20151106-story.html.
[353] John C. Fleming and Candice Kim, "Danger next Door: The Top 12 Air Toxics Used for Neighborhood Oil Drilling in Los Angeles" (Center for Biological Diversity, December 2017), http://www.biologicaldiversity.org/publications/papers/DangerNextDoor.pdf.

lined or are currently racially segregated.[354, 355, 356]

In February 2021, two historically disenfranchised rural Kern Counties communities, Arvin and Lamont, won inclusion in a community air protection law that compels power-sharing between California's regional air pollution districts and affected communities. The residents of Arvin and Lamont, surrounded by oil wells and refineries, suffer from some of the worst air pollution in the state. (See footnote 503.)

In Greeley, Colorado, a massive well pad housing 24 wells was sited near Bella Romera Academy, an elementary school in a low-income community where 82 percent of students are Latino, after earlier plans were scrapped for a site near a charter school where students are majority white and middle-class.[357] An analysis of state data in 2020 showed that benzene levels in the air near the school exceeded health-based limits 113 times, including spikes during four full school days in 2019.[358] Benzene is a known cause of leukemia.

In the Appalachian Basin, studies consistently find associations between fracking operations and poverty. In West Virginia and Pennsylvania, a geographic study found a higher concentration of drilling and fracking operations in impoverished communities but did not find differences with respect to race. "The results demonstrate that environmental injustice occurs in areas with unconventional wells in Pennsylvania with respect to the poor population."[359] These findings are supported by census tract data in western Pennsylvania showing that among nearly 800 gas wells, only two were drilled in communities where home values exceeded $200,000.[360] In Ohio, geographic evidence reveals that disposal wells for fracking wastewater are disproportionately located in lower-income, rural communities.[361] A 2023 study documented significant associations between elevated groundwater vulnerability and social vulnerability across the Appalachian Basin.[362] Environmental justice issues extend to downstream fracking

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[354] Bhavna Shamasunder and Jill E. Johnston, "The Imperative of Equitable Protection: Structural Racism and Oil Drilling in Los Angeles," *American Journal of Public Health*, September 7, 2023, e1–3, https://doi.org/10.2105/AJPH.2023.307405.

[355] Alique G. Berberian et al., "Race, Racism, and Drinking Water Contamination Risk From Oil and Gas Wells in Los Angeles County, 2020," *American Journal of Public Health*, August 31, 2023, e1–10, https://doi.org/10.2105/AJPH.2023.307374.

[356] Mary D. Willis and Jonathan J. Buonocore, "Fossil Fuel Racism: The Ongoing Burden of Oil and Gas Development in the Shadows of Regulatory Inaction," *American Journal of Public Health*, August 31, 2023, e1–3, https://doi.org/10.2105/AJPH.2023.307403.

[357] Julie Turkewitz, "In Colorado, a Fracking Boom and a Population Explosion Collide," *The New York Times*, May 31, 2018, https://www.nytimes.com/2018/05/31/us/colorado-fracking-debates.html.

[358] John Herrick, "Report: Cancer-Causing Benzene Spiked More than Once at Bella Romero," *The Colorado Independent*, March 11, 2020, https://www.coloradoindependent.com/2020/03/11/report-benzene-bella-romero/.

[359] Yelena Ogneva-Himmelberger and Liyao Huang, "Spatial Distribution of Unconventional Gas Wells and Human Populations in the Marcellus Shale in the United States: Vulnerability Analysis," *Applied Geography* 60 (2015): 165–74, https://doi.org/10.1016/j.apgeog.2015.03.011.

[360] Reid Frazier, "Is Fracking an Environmental Justice Issue?," The Allegheny Front, June 30, 2017, https://www.alleghenyfront.org/is-fracking-an-environmental-justice-issue/.

[361] Genevieve S. Silva, Joshua L. Warren, and Nicole Deziel, "Spatial Modeling to Identify Sociodemographic Predictors of Hydraulic Fracturing Wastewater Injection Wells in Ohio Census Block Groups," *Environmental Health Perspectives* 126, no. 6 (n.d.): 067008, https://doi.org/10.1289/EHP2663.

[362] Mario A. Soriano et al., "Social Vulnerability and Groundwater Vulnerability to Contamination From Unconventional Hydrocarbon Extraction in the Appalachian Basin," *GeoHealth* 7, no. 4 (April 2023): e2022GH000758, https://doi.org/10.1029/2022GH000758.

infrastructure. In 2018, community groups in North Carolina filed an environmental justice complaint against Dominion's Energy's $8 billion Atlantic Coast Pipeline, alleging the project poses disproportionate risk of harm to people of color. Thirteen percent of those living along the pipeline route are Native Americans in a state where Native Americans make up only 1.2 percent of the population.[363, 364] A compressor station in Virginia that would service this pipeline was proposed to be sited in the historically African-American community of Union Hill.[365] In January 2020, the 4th U.S. Circuit Court quashed the approval of this compressor station, noting that state regulators had failed to fully consider disproportionate harms to an environmental justice community. In July 2020, Dominion Energy canceled the Atlantic Coast pipeline project entirely and sold off assets.[366]

Meanwhile, Mountain Valley Pipeline's 75-mile Southgate Extension, which would ferry fracked gas from West Virginia between southern Virginia and North Carolina, called for two compressor stations that would disproportionately affect Black and Indigenous communities.[367, 368] In 2021, the North Carolina Department of Environmental Quality denied certification to the pipeline itself, the object of Indigenous-led opposition to the project.[369] However, this project was revived after Congress passed the Fiscal Responsibility Act that required fast-tracked approvals for the Mountain Valley Pipeline's main stem to which the Southgate pipeline is attached. In June 2023, the developers of the Southgate project requested a three-year extension on its mandatory completion date.[370] Similarly, Southgate's associated Lambert compressor station is now back in play even though the Virginia Air Pollution Control Board had, in December 2021, denied the compressor station project on environmental justice grounds.[371] In July 2023, more than 50 state legislators in the North Carolina General Assembly sent a letter to FERC reiterating the environmental justice issues posed by the proposed compressor station, which would be sited in an impoverished rural area along the Virginia-North Carolina border,

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[363] Phil McKenna, "Atlantic Coast Pipeline Faces Civil Rights Complaint after Key Permit Is Blocked," Inside Climate News, May 18, 2018, https://insideclimatenews.org/news/18052018/atlantic-coast-pipeline-natural-gas-civil-rights-environmental-justice-epa.
[364] Ryan E. Emanuel, "Flawed Environmental Justice Analyses," *Science* 375, no. 6348 (2017): 260, https://doi.org/10.1126/science/aao2684.
[365] Mary Finley-Brook et al., "Critical Energy Justice in US Natural Gas Infrastructuring," *Energy Research & Social Science* 41 (2018), https://doi.org/10.1016/j.erss.2018.04.019.
[366] Carlos Anchondo, Kristi E. Swartz, and Hannah Northey, "Decision to Kill Atlantic Coast Project Upends Natural Gas," Energy Wire, July 6, 2020, https://www.eenews.net/energywire/stories/1063513089.
[367] Karenna Gore, "The Common Wealth of Water," *Virginia Mercury*, October 18, 2021, https://www.virginiamercury.com/2021/10/18/the-common-wealth-of-water/.
[368] Alexa Sutton Lawrence, "Updated Community Impact Assessment of Lambert Compressor Station" (Land and Heritage Consulting, February 25, 2021), https://www.deq.virginia.gov/home/showpublisheddocument/5326/637499574094200000.
[369] Nick de la Canal, "NC Regulators Reject Natural Gas Pipeline Extension For Second Time," WFAE.org, May 1, 2021, https://www.wfae.org/energy-environment/2021-05-01/nc-regulators-reject-natural-gas-pipeline-extension-for-second-time.
[370] Adam Wagner, "With New Hope from Congress, Gas Pipeline Project in NC May Be Revived. What We Know.," *The News & Observer*, June 30, 2023, https://www.newsobserver.com/news/politics-government/article276460326.html.
[371] Sarah Vogelsong, "Virginia Regulatory Board Denies Mountain Valley Pipeline Compressor Station Permit," *Virginia Mercury*, December 3, 2021, https://www.virginiamercury.com/2021/12/03/virginia-regulatory-board-denies-mountain-valley-pipeline-compressor-station-permit/.

and noting that the project has not yet obtained an air quality permit.[372]

In 2020, FERC approved the Sabal Trail compressor station in the majority Black community in Albany, Georgia in a decision that provoked pointed criticism from the National Black Environmental Justice Network. The Commission also approved three LNG projects in Brownsville, Texas—even after finding that most of the people potentially harmed by one of these three projects and the associated pipeline were Latino and one-third lived below the poverty line.[373]

In Pennsylvania, the siting of fracking waste is correlated with economic deprivation. According to a 2022 study, fracking waste disposal operations are disproportionately located in deprived communities. Deprived communities also receive larger volumes of waste. Oil and gas rights owners are less likely to live in these communities, "adding evidence of a disparity between exposure and benefits" resulting from oil and gas development.[374]

The siting of power plants often reveals historical patterns of racial and economic bias. A 2022 study of 196 urban areas across the United States found that "red-lining"—racialized appraisals of investment risk—by the U.S. federal Home Owners' Loan Corporation in the 1930s strongly influenced the subsequent siting of coal- and gas-fired power plants. In this way, racism in the housing market contributes to disparities in exposure to power plant emissions. These patterns are replicated in many other studies.[375] In Pennsylvania, gas-fired power plants are disproportionately located in low-income and minority communities.[376] Across California, gas-fired power plants are disproportionately located in disadvantaged communities, as classified by an environmental justice screening tool developed by the state Office of Environmental Health Hazard Assessment.[377] Fully half of California's fleet of gas-fired peaker plants are located in disadvantaged communities. Designed to ramp up quickly to meet peak electrical demand, peaker plants have higher emission rates of both greenhouse gases and smog-creating air pollutants when running than do continuously operating gas-fired plants.[378]

Similarly, In Arizona, Massachusetts, New Jersey, and New York, peaker plants tend to be located in minority and low-income communities or in areas the state has otherwise designated as environmental justice communities.[379] In southern Virginia, two gas-fired power plants

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[372] John Deem, "North Carolina Legislators Urge Feds to Block Triad Pipeline," *Governing*, July 25, 2023, https://www.governing.com/climate/north-carolina-legislators-urge-feds-to-block-triad-pipeline.
[373] Arianna Skibell and Niina H. Farah, "FERC Faces Environmental Justice Reckoning," E&E News, July 31, 2020, https://web.archive.org/web/20200801222929/https://www.eenews.net/stories/1063659305.
[374] Wil Lieberman-Cribbin et al., "Multiple Dimensions of Environmental Justice and Oil and Gas Development in Pennsylvania," *Environmental Justice*, December 23, 2022, env.2022.0041, https://doi.org/10.1089/env.2022.0041.
[375] Lara J. Cushing et al., "Toxic Tides and Environmental Injustice: Social Vulnerability to Sea Level Rise and Flooding of Hazardous Sites in Coastal California," *Environmental Science & Technology*, May 2, 2023, acs.est.2c07481, https://doi.org/10.1021/acs.est.2c07481.
[376] Nextgen Climate America, & PSE Healthy Energy, "Our Air: Health and Equity Impacts of Pennsylvania's Power Plants," n.d., https://www.psehealthyenergy.org/wp-content/uploads/2017/11/NGCA-PSE-Our-Air-Health-and-Equity-Impacts-PA-2016-0710.pdf.
[377] PSE Healthy Energy, "Natural Gas Power Plants in California's Disadvantaged Communities," research brief, April 2017, https://www.psehealthyenergy.org/wp-content/uploads/2017/04/CA.EJ_.Gas_.Plants.pdf.
[378] PSE Healthy Energy, "California Peaker Power Plants," May 2020, https://www.psehealthyenergy.org/wp-content/uploads/2020/05/California.pdf.
[379] PSE Healthy Energy, "Energy Storage Peaker Plant Replacement Project," PSE: Bringing Science to Energy Policy, n.d., https://www.psehealthyenergy.org/our-work/energy-storage-peaker-plant-replacement-project/.

proposed for an impoverished majority Black community in Charles City County have been canceled due to environmental justice concerns.[380]

In New Orleans, the city council approved the construction of Entergy's gas-fired power plant to be built amid largely African American and Vietnamese-American neighborhoods over the opposition of community groups who had both questioned the necessity of the plant and denied that meaningful input from local residents—or an investigation into clean energy alternatives—had ever taken place. The gas plant would annually release more than one million pounds of toxic air pollution and more than 700 million pounds of greenhouse gases. In November 2019, a judge voided the council's approval, ruling that crucial public meetings had, in fact, been illegally packed with paid pro-gas actors indirectly hired by Entergy.[381] In February 2020, a state appellate court overturned that decision and let stand the city council's approval of construction.[382]

In New York City, gas-fired peaker plants located in low-income communities were targeted for replacement with renewable energy and battery storage technologies after the New York Power Authority signed an October 2020 agreement with a coalition of environmental justice groups.[383] However, three years later, the halting pace of New York's energy transition may delay the retirement of some of them.[384] Peaker plants operate intermittently at times of peak energy demand and, all together, contribute more than one third of New York State's nitrogen oxide emissions when operating.

The environmental injustices of downstream fracking infrastructure extend to natural gas distribution systems. Across 13 urban areas within the United States, leaks from natural gas pipelines servicing residential buildings were significantly greater in communities of color and in communities with lower median household incomes, even after accounting for housing age.[385]

Apart from disparities circumscribed by race and income, fracking raises fundamental questions of human rights. A comprehensive analysis that charts the international legal development of water rights as they apply to oil and gas extraction concluded that the right to water for residents living near fracking sites is "likely to be severely curtailed." This analysis emphasizes that access to clean and safe drinking water is codified by the United Nations

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[380] Sarah Vogelsong, "Chickahominy Power Cancels Plans for Natural Gas Plant in Charles City," *Virginia Mercury*, March 17, 2022, https://www.virginiamercury.com/blog-va/chickahominy-power-cancels-plans-for-natural-gas-plant-in-charles-city/.
[381] Ivan Penn, "Natural Gas or Renewables? New Orleans Choice Is Shadowed by Katrina," *The New York Times*, November 8, 2019, sec. Energy & Environment, https://www.nytimes.com/2019/11/08/business/energy-environment/gas-power-plants.html.
[382] Jessica Williams, "New Orleans Council Violated Law, but Vote on Entergy Power Plant Still OK, Judges Rule," *The Times-Picayune*, February 13, 2020, https://www.nola.com/news/politics/article_13af7070-4e81-11ea-bf49-db5ebb91c620.html.
[383] New York Power Authority, "NYPA and Environmental Justice Groups Agree to Explore Options for Transitioning NYPA's Natural Gas 'peaker' Plants to Cleaner Energy Technologies," press release, October 13, 2020, https://www.nypa.gov/news/press-releases/2020/20201013-ej.
[384] Colin Kinniburgh, "As New York Lags on Climate Goals, Some Dirty Plants May Stay Open Past Deadline," *New York Focus*, June 14, 2023, https://nysfocus.com/2023/06/14/new-york-air-pollution-climate-peaker-plant.
[385] Zachary D. Weller et al., "Environmental Injustices of Leaks from Urban Natural Gas Distribution Systems: Patterns among and within 13 U.S. Metro Areas," *Environmental Science & Technology* 56, no. 12 (June 21, 2022): 8599–8609, https://doi.org/10.1021/acs.est.2c00097.

General Assembly as a human right essential to the full development of life and all other human rights. And yet, the fracking industry does not bear the true societal cost of water in their production decisions.

Accordingly, the authors argue, ownership of this essential-to-life resource is effectively transferred from society to industry, with no protection for this essential human right. In the United States alone, "there is considerable evidence that the human right to water will be seriously undermined by the growth of the unconventional oil and gas industry, and given its spread around the globe, this could soon become a global human rights issue."[386]

Three international human rights bodies have called for prohibitions on fracking. In February 2019, the Committee on Elimination of Discrimination Against Women, which monitors the implementation of the 1979 United Nations treaty that serves as an international bill of rights for women, called on the United Kingdom to ban fracking on the ground that fracking damages communities and imperils the climate in ways that disproportionately harm women and girls living in rural areas.[387, 388] In October 2018, the United Nations Committee on Economic, Social and Cultural Rights warned Argentina that its plans for large-scale fracking in the Vaca Muerta Shale region would create adverse economic and cultural rights impacts on the indigenous Mapuche people.[389] In May 2018, the Permanent People's Tribunal, a Rome-based forum focused on human rights violations, issued an advisory opinion based on a two-year investigation that collected testimonies and reports from scientists and fracking-impacted communities.

In the words of the Tribunal,

> The evidence clearly demonstrates that the processes of fracking contribute substantially to anthropogenic harm, including climate change and global warming, and involve massive violations of a range of substantive and procedural human rights and the rights of nature. Thus the industry has failed to fulfill its legal and moral obligations…. The dangers of fracking to the rights of people, communities, and nature are inherent in the industry…. We will go beyond the call for a moratorium and recommend that fracking should be banned.[390]

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[386] Robert C. Palmer, Damien Short, and Walter E. Ted Auch, "The Human Right to Water and Unconventional Energy," *International Journal of Environmental Research and Public Health* 15, no. 9 (n.d.): 1858, https://doi.org/10.3390/ijerph15091858.

[387] United Nations Committee on the Elimination of Discrimination Against Women, "List of Issues in Relation to the Eighth Periodic Report of the United Kingdom of Great Britain and Northern Ireland," UN Treaty Body Database, United Nations Human Rights Treaty Bodies, July 27, 2018, https://tbinternet.ohchr.org/_layouts/15/treatybodyexternal/Download.aspx?symbolno=CEDAW%2fC%2fGBR%2fCO%2f8&Lang=en.

[388] Center for International Environmental Law, "UN Body Recommends UK Consider Complete Fracking Ban to Protect Human Rights," press release, March 13, 2018, https://www.ciel.org/news/un-body-recommends-uk-consider-complete-fracking-ban-to-protect-human-rights/.

[389] Center for International Environmental Law, "CIEL Statement on the Committee on Economic, Social, and Cultural Rights (CESCR)'s Recommendations for the State of Argentina Regarding Its Vaca Muerta Shale Gas Development," press release, October 19, 2018, https://www.ciel.org/news/ciel-statement-on-the-committee-on-economic-social-and-cultural-rights-cescrs-recommendations-for-the-state-of-argentina-regarding-its-vaca-muerta-shale-gas-development/.

[390] Permanent Peoples' Tribunal, "Session on Human Rights, Fracking and Climate Change—Advisory Opinion," May 14, 2018, http://permanentpeoplestribunal.org/wp-content/uploads/2019/04/AO-final-12-APRIL-2019.pdf.

In October 2021, the United Nations Human Rights Council, an intergovernmental body within the United Nations system charged with addressing situations of human rights violations, passed a resolution recognizing the right to a healthy and sustainable environment as a basic human right, and in a second resolution, established a Special Rapporteur dedicated specifically to the human rights impacts of climate change.[391]

16) Carbon capture and storage fails to mitigate the dangers of fracking.

In the United States, gas and oil companies have turned to carbon capture and storage (CCS) as a method of offsetting, on paper, their greenhouse gas emissions without ending fossil fuel extraction or combustion. This technology is linked to fracking in several ways and has received major support by the Biden administration.[392] In August 2023, the U.S. Department of Energy announced it would spend up to $1.2 billion on commercial-scale direct air capture demonstration facilities in Louisiana and Texas.[393]

In contrast to direct air capture of ambient carbon dioxide, CCS is a process by which complex machinery, typically powered by a gas-fired turbine, is added to an existing point source of carbon dioxide, such as the smoke stack of a power plant. Its purpose is to catch some of the carbon dioxide that would otherwise be released into the atmosphere from fossil-fuel combustion, separate it from other emissions, pressurize it into a liquid, and then transport the liquefied carbon dioxide through pipelines to an underground repository or to oil fields for use in oil extraction operations. CCS relies on multiple technologies. Carbon dioxide emissions may be captured by membranes, for example, or, more typically, absorbed into a solvent.[394]

All CCS methods are hugely expensive, with carbon capture from a gas-fired power plant costing $49-$150 per ton of carbon captured.[395] Because there is no market for waste carbon dioxide, CCS must be supported by massive public subsidies, as, for example, by offering tax credits. Under current law, Section 45Q of the Internal Revenue Code supports CCS efforts by offering a tax credit for each ton of carbon dioxide captured and stored. In 2022, as part of the

[391] Office of the High Commissioner, "Bachelet Hails Landmark Recognition That Having a Healthy Environment Is a Human Right," United Nations Human Rights, October 8, 2021, https://www.ohchr.org/EN/NewsEvents/Pages/DisplayNews.aspx?NewsID=27635&LangID=E).
[392] Council on Environmental Quality, "Council on Environmental Quality Report to Congress on Carbon Capture, Utilization, and Sequestration" (The White House, June 20, 2021), https://www.whitehouse.gov/wp-content/uploads/2021/06/CEQ-CCUS-Permitting-Report.pdf.
[393] Department of Energy, "Biden-Harris Administration Announces Up To $1.2 Billion For Nation's First Direct Air Capture Demonstrations in Texas and Louisiana," Energy.gov, August 11, 2023, https://www.energy.gov/articles/biden-harris-administration-announces-12-billion-nations-first-direct-air-capture.
[394] Stefano E. Zanco et al., "Postcombustion CO_2 Capture: A Comparative Techno-Economic Assessment of Three Technologies Using a Solvent, an Adsorbent, and a Membrane," *ACS Engineering Au* 1, no. 1 (October 20, 2021): 50–72, https://doi.org/10.1021/acsengineeringau.1c00002.
[395] Jonathan M. Moch, William Xue, and John P. Holdren, "Carbon Capture, Utilization, and Storage: Technologies and Costs in the U.S. Context," Policy Brief (Harvard Kennedy School Belfer Center for Science and International Affairs, January 2022), https://www.belfercenter.org/publication/carbon-capture-utilization-and-storage-technologies-and-costs-us-context.

Inflation Reduction Act, these tax credits were increased and eligibility thresholds loosened, further incentivizing carbon capture projects.[396]

As a highly experimental set of unproven technologies, CCS has largely failed to reach its promised rates of capture. Claims that CCS can reduce carbon dioxide emissions by 90 percent or more have never been realized commercially, with pilot projects capturing as little as 30 percent. Currently only 27 commercial CCS facilities are operational worldwide, of which twelve are in the United States. Of these U.S. facilities, four are used for natural gas processing, three for ethanol production, three for fertilizer production, one for synthesis gas production, and one in hydrogen production. Only one, the Illinois Industrial Carbon Capture and Storage Project, actually stores the carbon it captures, and it has consistently failed to reach its promised goal each year.[397] A September 2022 analysis of 13 different carbon capture and storage projects around the world found that all were underperforming and that, as a technique to extend the life of fossil-fuel plants, financial and technical risks were considerable.[398] Similarly, a September 2023 review of 12 major carbon capture projects, including six in the United States, found that none actually reduced carbon dioxide emissions, most used the captured carbon to extract more oil, and cost overruns were typical.[399]

Capturing carbon dioxide from gas-fired power plants or other types of fracking infrastructure, including LNG terminals, has not proceeded past demonstration projects. No commercial-scale projects are currently operating for utilities. Indeed, CCS has largely failed for coal-fired power plants and, for gas-fired plants, would require massive investment, complex infrastructure, and further federal subsidies.[400]

The flagship demonstration project for CCS, at Chevron's $54 billion Gorgon LNG plant in Western Australia, has been plagued with technical problems and was operating at only half-capacity in 2021, having buried only 30 percent of the carbon dioxide it generated since 2016. Failing to meet its five-year target for carbon dioxide injection rates, Chevron was ultimately forced to purchase carbon offset credits as a penalty.[401, 402] Data released in 2022 showed a sharp decline in stored CO2 at the plant's underground reservoir over the past three years and a

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[396] Petya Trendafilova, "What Is The 45Q Tax Credit?," *Carbon Herald*, June 26, 2023, https://carbonherald.com/what-is-45q-tax-credit/.
[397] Angela C. Jones and Ashley J. Lawson, "Carbon Capture and Sequestration (CCS) in the United States" (Congressional Research Service, October 18, 2021), https://sgp.fas.org/crs/misc/R44902.pdf.
[398] Bruce Robertson and Milad Mousavian, "The Carbon Capture Crux: Lessons Learned" (Institute for Energy Economics and Financial Analysis, September 1, 2022), https://ieefa.org/resources/carbon-capture-crux-lessons-learned.
[399] Michael Buchsbaum and Edward Donnelly, "Fossil Fuel Companies Made Bold Promises to Capture Carbon. Here's What Actually Happened.," *DeSmog*, September 25, 2023, https://www.desmog.com/2023/09/25/fossil-fuel-companies-made-bold-promises-to-capture-carbon-heres-what-actually-happened/.
[400] U.S. Government Accountability Office, "Carbon Capture and Storage: Actions Needed to Improve DOE Management of Demonstration Projects" (U.S. Government Accountability Office, December 2021), https://www.gao.gov/assets/gao-22-105111.pdf.
[401] Josh Lewis, "Chevron's Flagship Gorgon CCS Project Still Failing to Live up to Expectations," *Upstream*, February 10, 2022, https://www.upstreamonline.com/energy-transition/chevrons-flagship-gorgon-ccs-project-still-failing-to-live-up-to-expectations/2-1-1166185.
[402] Sonali Paul, "Chevron, Partners to Fork out for Carbon Offsets for Gorgon LNG Carbon Capture Shortfall," Reuters, November 10, 2021, https://www.reuters.com/business/sustainable-business/chevron-invest-29-mln-address-co2-injection-shortfall-australia-lng-site-2021-11-11/.

concurrent rise in greenhouse gas emissions from the sites.[403] Here in the United States, the sole utility-scale CCS project, the Petra Nova coal-fired plant in Texas, shut down in 2020 after oil prices crashed. Petra Nova pumped its captured carbon dioxide to the Permian Basin to assist in oil extraction operations 80 miles away, which were largely suspended during the pandemic.[404] Petra Nova was restarted in September 2023 after oil prices rebounded. A 2020 review of more than 200 papers on carbon-capturing technology published in scientific journals concluded that the failures of CCS are systemic and irremediable. Because it can never store more than it captures, point-source CCS is not a negative emissions technology and cannot significantly reduce atmospheric carbon dioxide. Indeed, as currently practiced, CCS is net additive, releasing into the atmosphere more carbon dioxide than it removes.[405]

A 2021 study found that equipping a coal plant with carbon-capture technology would, over a 20-year period, result in only a 10 percent reduction in carbon dioxide entering the atmosphere compared to a coal plant operating without CCS.[406] Further, the CCS equipment is itself a source of greenhouse gas emissions, which are unaccounted for in most assessments of CCS climate impacts. Because powering this equipment is energy intensive, CCS also makes local air pollution worse. The emissions from the gas turbine that powers the capture equipment are themselves not captured, nor are the methane leaks from the turbine itself, nor are the upstream methane emissions from extracting and collecting the natural gas to run the turbine. Further, extra energy is needed to run the carbon-capturing machinery. For example, CCS requires 10 to 20 percent of a power plant's energy output.[407] Hence, a CCS-equipped facility, such as a gas-fired power plant, will consume more power and hence generate more air pollution, including soot and smog-producing vapors. Unlike carbon dioxide, these additional co-pollutants are not collected and captured, and they pose additional health threats to local residents. The total social cost (equipment plus health plus climate cost) of a coal plant outfitted with gas-powered CCS equipment is over twice that of wind replacing coal directly (See footnote 405.)

Because power plants and other heavy industries targeted for CCS are disproportionately located in low-income neighborhoods and communities of color, CCS is an environmental justice issue.[408] In essence, CCS prolongs the life of major sources of pollution, reduces carbon dioxide emissions only modestly, and increases the levels other deadly co-pollutants linked to asthma, stroke, heart attack risk, and preterm birth.

The dangers of CCS to public health and the climate continue during the transportation and storage phases. Once collected, the captured carbon is pressurized to 1,000 pounds per square

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[403] Chevron, "Gorgon Gas Development and Jansz Feed Gas Pipeline: Environmental Performance 2022," November 4, 2022, https://australia.chevron.com/-/media/australia/our-businesses/documents/gorgon-gas-development-and-jansz-feed-gas-pipeline-environmental-performance-report-2022.pdf.
[404] Kevin Robinson-Avila, "Debating the Promise and Perils of Carbon Capture in New Mexico," *Albuquerque Journal*, February 5, 2022, https://www.abqjournal.com/2467622/the-promise-and-perils-of-carbon-capture.html.
[405] June Sekera and Andreas Lichtenberger, "Assessing Carbon Capture: Public Policy, Science, and Societal Need: A Review of the Literature on Industrial Carbon Removal," *Biophysical Economics and Sustainability* 5, no. 3 (September 2020): 14, https://doi.org/10.1007/s41247-020-00080-5.
[406] Mark Z. Jacobson, "The Health and Climate Impacts of Carbon Capture and Direct Air Capture," *Energy & Environmental Science* 12, no. 12 (2019): 3567–74, https://doi.org/10.1039/C9EE02709B.
[407] Suraj Vasudevan et al., "Energy Penalty Estimates for CO2 Capture: Comparison between Fuel Types and Capture-Combustion Modes," *Energy* 103 (May 2016): 709–14, https://doi.org/10.1016/j.energy.2016.02.154.
[408] Heather Payne, "Chasing Squirrels in the Energy Transition," *Environmental Law* 52 (2022), https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3998197.

inch and thereby turned into liquid for transport through pipelines. These pressurized pipelines may leak or rupture in ways that cause asphyxiation hazards for nearby residents due to the ability of carbon dioxide to displace oxygen. In February 2020, a carbon dioxide pipeline ruptured in Satartia, Mississippi, hospitalizing 49 people. Many victims continue to suffer long-lasting health problems.[409] The carbon dioxide within this particular pipeline was also contaminated with hydrogen sulfide gas. No federal regulations regulate the presence of chemical impurities in liquefied carbon dioxide transported by pipeline.[410] In an October 2023 letter to President Biden, eleven Democratic members of Congress asked for a moratorium on the construction of carbon dioxide pipelines until safety regulations can be updated. Noting that carbon dioxide is an invisible, odorless asphyxiant, the letter warns that "transporting CO2 under the extremely high pressure required to maintain a supercritical fluid state can cause ruptures that 'unzip' a pipeline over long distances."[411]

A May 2023 study compared the failure rate of pressurized oil and gas pipelines with that of pressurized carbon dioxide pipelines in regard to puncture size. The team found that CO2 pipelines are more likely to experience smaller puncture failures, resulting in smaller leaks that are harder to detect and therefore more prolonged. "This directly impacts the preventive and emergency response planning required especially in the case of buried CO2 pipelines where small leaks can remain undetected for long periods."[412] Earlier research shows that leakage of carbon dioxide gas through small holes in buried pipelines are difficult to detect, increasing their threat to both climate and public health.[413]

Widespread development of CCS at commercial scale would require massive pipeline construction. An oil and gas industry-funded study from Princeton University proposed a pathway to net zero carbon by 2050 that would necessitate 66,000 miles of carbon dioxide pipelines, including more than 13,000 miles of interstate lines, heading to thousands of deep-earth burial sites.[414, 415]

In the rural Midwest, carbon capture pipelines have sparked widespread resistance among landholders, many of whom are concerned about their safety and also object to the use of

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[409] Dan Zegart, "The Gassing of Satartia," *Huffington Post*, October 26, 2021, https://www.huffpost.com/entry/gassing-satartia-mississippi-co2-pipeline_n_60ddea9fe4b0ddef8b0ddc8f.
[410] Code of Federal Regulations, "Part 195—Transportation of Hazardous Liquids by Pipeline," ECFR.gov, July 27, 1981, https://www.ecfr.gov/current/title-49/subtitle-B/chapter-I/subchapter-D/part-195.
[411] "Democrats in Congress Ask Biden for Moratorium on Carbon Pipeline Permits," *Reuters*, October 3, 2023, https://www.reuters.com/markets/commodities/democrats-congress-ask-biden-moratorium-carbon-pipeline-permits-2023-10-03/.
[412] Jiahuan Yi, Sergey Martynov, and Haroun Mahgerefteh, "Puncture Failure Size Probability Distribution for CO2 Pipelines," *International Journal of Greenhouse Gas Control* 125 (May 2023): 103889, https://doi.org/10.1016/j.ijggc.2023.103889.
[413] Zhenyi Liu et al., "Experimental Study on the Leakage Temperature Field of Buried CO2 Pipelines," *Environmental Science and Pollution Research* 30, no. 27 (May 6, 2023): 70288–302, https://doi.org/10.1007/s11356-023-27289-3.
[414] Eric Larson et al., "Net-Zero America: Potential Pathways, Infrastructure, and Impacts (Interim Report)" (Princeton University, December 15, 2020), https://netzeroamerica.princeton.edu/img/Princeton_NZA_Interim_Report_15_Dec_2020_FINAL.pdf.
[415] Elizabeth Abramson, Dane McFarlane, and Jeff Brown, "Transport Infrastructure for Carbon Capture and Storage" (Great Plains Institute, June 2020), https://www.betterenergy.org/wp-content/uploads/2020/06/GPI_RegionalCO2Whitepaper.pdf.

eminent domain to seize farmland for pipeline routes.[416] These objections have fueled political opposition. In September 2023, the South Dakota Public Utilities Commission denied a permit for a 469-mile section of carbon dioxide pipeline that is part of a planned 2,000-mile carbon capture network that extends through five states as part of the Summit Carbon Solutions project. This decision follows North Dakota's denial of a siting permit for a 320-mile section on its side of the state border.[417, 418] The Summit pipeline would ferry carbon dioxide to North Dakota for burial. In October 2023, citing regulatory uncertainty in Illinois, Navigator CO2 Ventures announced a decision to suspend the permit process for its proposed carbon capture pipeline in Iowa. The Navigator pipeline project, which was likewise denied a permit in South Dakota, intends to ferry captured carbon through five states for burial in central Illinois.[419]

Once the carbon dioxide waste is buried in geological formations, its long-term behavior is unknown.[420] Under Section 45Q of the Internal Revenue Code, companies claiming tax credits for its capture do not need to ensure that the carbon dioxide stays in the ground.[421] And there are reasons to believe it may not.[422] Some fraction of the injected carbon dioxide will begin to mineralize if certain ions are present for the necessary chemical reactions to occur, but some leakage will inevitably occur during long-term storage.[423] Also, when in the presence of moisture, carbon dioxide converts to carbonic acid and can react chemically, leaching heavy metals and dissolving rock and cement.[424, 425] If fissures in caprocks or abandoned wells offer pathways for leakage, liquid carbon dioxide waste could potentially acidify and permanently contaminate underground aquifers, poisoning drinking water for millions of people. In the event of a technological failure or earthquake, carbon dioxide could gasify and be released back to the

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[416] Anna Mattson, "Pipelines Touted as Carbon Capture Solution Spark Uncertainty and Opposition," *Scientific American*, October 1, 2023, https://www.scientificamerican.com/article/pipelines-touted-as-carbon-capture-solution-spark-uncertainty-and-opposition/.
[417] Jack Dura, "South Dakota Panel Denies Application for CO2 Pipeline; Summit to Refile for Permit," Associated Press, September 11, 2023, https://apnews.com/article/south-dakota-north-dakota-co2-pipeline-summit-827c7418edba5a4ecbd7501be02d84f9.
[418] Jack Dura, "North Dakota Regulators Deny Siting Permit for Summit Carbon Dioxide Pipeline; Company Will Reapply," Associated Press, August 4, 2023, https://apnews.com/article/north-dakota-carbon-dioxide-pipeline-29d15d0d29782f9f28b7907b6bb1896e.
[419] Donnelle Eller, "Landowners Deserve to Know More about Navigator's Pipeline Pause, Attorney Says," *Des Moines Register*, October 2, 2023, https://www.desmoinesregister.com/story/money/business/2023/10/02/navigator-should-give-landowners-more-information-about-carbon-capture-pipeline-pause-sierra-club/71035203007/.
[420] Juan Alcalde et al., "Estimating Geological CO2 Storage Security to Deliver on Climate Mitigation," *Nature Communications* 9, no. 1 (2018): 2201, https://doi.org/10.1038/s41467-018-04423-1.
[421] Nicholas Kusnetz, "Fossil Fuel Companies Are Quietly Scoring Big Money for Their Preferred Climate Solution: Carbon Capture and Storage," *Inside Climate News*, August 17, 2021, https://insideclimatenews.org/news/17082021/carbon-capture-storage-fossil-fuel-companies-climate/.
[422] Terry L. Jones and Pam Radtke, "A Known Risk: How Carbon Stored Underground Could Find Its Way Back Into the Atmosphere," *Inside Climate News*, September 26, 2023, https://insideclimatenews.org/news/26092023/a-known-risk-how-carbon-stored-underground-could-find-its-way-back-into-the-atmosphere/.
[423] Lei Li et al., "Research Progress and Prospect of Carbon Dioxide Utilization and Storage Based on Unconventional Oil and Gas Development," *Energies* 15, no. 24 (December 11, 2022): 9383, https://doi.org/10.3390/en15249383.
[424] John Fogarty, "Health and Safety Risks of Carbon Capture and Storage," *JAMA* 303, no. 1 (2010): 67, https://doi.org/10.1001/jama.2009.1951.
[425] Peilin Cao, Zuleima T. Karpyn, and Li Li, "The Role of Host Rock Properties in Determining Potential CO2 Migration Pathways," *International Journal of Greenhouse Gas Control* 45 (2016): 18–26, https://doi.org/10.1016/j.ijggc.2015.12.002.

atmosphere.[426] Storage of liquified carbon dioxide in deep geological formations is, like the injection of fracking wastewater, linked to increased risks for earthquakes that could compromise the seal integrity of these repositories.

Even absent significant seismic activity, carbon sequestration itself can create pressure build-up large enough to break the reservoirs' seals, releasing the stored carbon dioxide. Old wells, boreholes, and faults are the most common pathways for free-form carbon dioxide to escape to the surface.[427, 428] To be effective, carbon dioxide repositories need to be monitored for carbon dioxide leakage over long periods and require a leak rate of less than one percent per thousand years.[429] The U.S. Department of Energy is currently examining 19 sites in the midwestern United States to serve as possible storage depots for carbon dioxide waste.[430]

A 2023 investigation by the Institute for Energy Economics and Financial Analysis (IEEFA) found that CO2 storage projects may carry more uncertainty and risk than drilling for oil or gas, given the lack of knowledge about the capacity of subsurface geological formations to keep CO2 in the ground permanently. The IEEFA report notes that two long-running CCS projects in Norway, once hailed as success stories, are now mired in unexpected problems. In the Sliepner facility, operational since 1996, CO2 from the underground storage area is now migrating upwards, while the Snøhvit facility, operational since 2008, has proven to have nine-fold less storage capacity than originally forecast and will fill up far sooner than predicted.[431]

This failure to estimate carbon dioxide storage capacity accurately is not necessarily the result of computational errors. "Subsurface conditions which exist at a given point on the Earth are specific to that place; even then, any information obtained about that place is only a snapshot in time. The Earth moves and strata can change, according to the report's author Grant Hauber. "While the oil and gas industry is used to dealing with uncertainty in exploration and production, the risks multiply when trying to place something like CO2 back in the ground."[432]

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[426] Physicians for Social Responsibility Los Angeles, "Danger Ahead: The Public Health Disaster That Awaits From Carbon Capture and Sequestration (CCS)," PSR-LA.org, February 10, 2022, https://www.psr-la.org/danger-ahead-the-public-health-disaster-that-awaits-from-carbon-capture-and-sequestration-ccs/.
[427] Peter Kelemen et al., "An Overview of the Status and Challenges of CO2 Storage in Minerals and Geological Formations," *Frontiers in Climate* 1 (November 15, 2019): 9, https://doi.org/10.3389/fclim.2019.00009.
[428] Curtis M. Oldenburg, Preston D. Jordan, and Elizabeth Burton, "Recommendations for Geologic Carbon Sequestration in California: I. Siting Criteria and Monitoring Approaches, II. Example Application Case Study," June 15, 2017, https://ww2.arb.ca.gov/sites/default/files/2018-12/LBNL_CARB_QM_Final_Report_6-15-17.pdf?msclkid=0b14779dabb511ec9b6ebda6eea66910.
[429] Mark D. Zoback and Steven M. Gorelick, "Earthquake Triggering and Large-Scale Geologic Storage of Carbon Dioxide," *Proceedings of the National Academy of Sciences* 109, no. 26 (June 26, 2012): 10164–68, https://doi.org/10.1073/pnas.1202473109.
[430] "Carbonsafe," National Energy Technology Laboratory, n.d., https://www.netl.doe.gov/coal/carbon-storage/storage-infrastructure/carbonsafe.
[431] Grant Hauber, "Norway's Sleipner and Snøhvit CCS: Industry Models or Cautionary Tales?" (Institute for Energy Economics and Financial Analysis, June 14, 2023), https://ieefa.org/resources/norways-sleipner-and-snohvit-ccs-industry-models-or-cautionary-tales.
[432] Rachel Williamson, "Problems at Two CCS 'Success Stories' Cast Fresh Doubt on the Technology," *Renew Economy*, June 16, 2023, https://reneweconomy.com.au/problems-at-two-ccs-success-stories-cast-fresh-doubt-on-the-technology/.

In addition to providing the gas for carbon dioxide-capturing turbines, fracking is linked to CCS in three other ways. First, the primary current use of CCS is to enhance oil extraction from aging wells. Indeed, all but one of the 12 CCS projects in the United States use the captured carbon dioxide for enhanced oil recovery in which captured carbon dioxide is pumped into partially depleted oil wells to extract more oil by decreasing its viscosity.[433] Indeed, enhanced oil recovery is the only existing commercially available market for millions of tons of captured carbon dioxide, and the downstream emissions from burning this oil, which would otherwise remain underground, is not accounted for in CCS "net-zero" models.

The use of captured carbon to force more oil from depleted wells has created incongruities and legal loopholes in the regulations governing CO2 sequestration and undermines the assumption of permanent storage. As documented in a 2023 white paper, Class VI Underground Injection Control Permits are the primary regulatory device that applies to carbon sequestration operations. However, these permits were intended to protect sources of underground drinking water supplies, not provide for the permanent warehousing of carbon dioxide for purposes of protecting the climate. Further, these regulations allow operators to circumvent detailed Class VI well requirements and instead store CO2 in more lightly regulated Class II wells with little government oversight. Class II wells are typically used to inject fluids from oil and gas extraction activities, including fracking waste, into geological formations. However, the Inflation Reduction Act includes tax incentives designed to encourage CO2 storage in Class II wells, either through injection for enhanced recovery of oil or gas or injection for the sole purpose of long-term storage.[434, 435]

Second, carbon dioxide in its supercritical form can be used as a substitute for water as the agent of fracking itself.[436, 437]

Third, CCS is used to produce "blue hydrogen" from fracked gas. There are several methods for producing hydrogen fuel. One uses electrolysis of water powered by renewable energy to produce hydrogen and oxygen. This is so-called "green hydrogen." The other two most common methods use natural gas as a starting point. In the first, hydrogen fuel is manufactured by using heat and pressure to convert the methane in natural gas to hydrogen and prodigious amounts of carbon dioxide, which is released into the atmosphere. The hydrogen produced in this way is called "gray hydrogen." "Blue hydrogen" is produced in the same way as gray hydrogen, but with some of its carbon dioxide emissions captured and stored. As of 2021, just four facilities

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[433] Leah Douglas, "Factbox: Biden Administration Sees Carbon Capture as Key Tool in Climate Fight," Reuters, February 7, 2022, https://www.reuters.com/business/environment/biden-administration-sees-carbon-capture-key-tool-climate-fight-2022-02-07/.

[434] Keri Powell, "Use of Class II Underground Injection Control (UIC) Wells for Long-Term CO2 Geologic Sequestration/Storage," June 7, 2023, https://drive.google.com/file/d/1jpdqmstzzRsp_t1AdoAPi091BmwstKQS/view.

[435] United States Environmental Protection Agency, "Class II Oil and Gas Related Injection Wells," EPA.gov, August 22, 2022, https://www.epa.gov/uic/class-ii-oil-and-gas-related-injection-wells.

[436] Mandira Agarwal and Vamsi Krishna Kudapa, "Comparing the Performance of Supercritical CO2 Fracking with High Energy Gas Fracking in Unconventional Shale," *MRS Energy & Sustainability* 9, no. 2 (September 2022): 461–68, https://doi.org/10.1557/s43581-022-00043-x.

[437] Bing Hou and Zhuang Cui, "Vertical Fracture Propagation Behavior upon Supercritical Carbon Dioxide Fracturing of Multiple Layers," *Engineering Fracture Mechanics* 277 (January 2023): 108913, https://doi.org/10.1016/j.engfracmech.2022.108913.

globally—two in Alberta, one in Texas, and one in Oklahoma—used natural gas with CCS to manufacture blue hydrogen. In all cases the estimated proportion of carbon dioxide captured is below 50 percent.[438]

Although blue hydrogen has been touted as a climate solution, recent research indicates that its carbon footprint is 20 percent greater than burning natural gas directly. Furthermore, combustion emissions from the machinery needed to run the carbon and capture equipment, plus fugitive methane emissions, make blue hydrogen a dirtier fuel than burning methane alone.[439] Greenhouse gas emissions from the manufacture of hydrogen using methane as a starting point are substantial, even with carbon capture and storage.[440]

In sum, CCS functions as a fossil fuel subsidy, entrenches fossil fuel demand, impedes the phase-out of fracking, requires massive public investment, captures far less carbon dioxide than claimed, and suffers from incomplete emissions accounting. It also harms the environment and further endangers public health through its emissions of conventional pollutants and need for massive buildout of pipelines. CCS strategies fail to account for upstream fugitive methane emissions as well as for carbon dioxide emissions created from the combustion of oil retrieved by injecting captured carbon dioxide into otherwise depleted wells.[441] CCS is aimed at prolonging drilling and fracking for oil and natural gas and does not address the many public health, climate, and environmental justice problems created by fracking, as detailed in this Compendium. In these ways, CCS enables fracking and is an expensive, dangerous diversion away from renewable energy investments.[442]

17) Combustion of fracked gas inside homes via kitchen stoves, hot water heaters, and furnaces creates additional health and climate harms.

With natural gas burned in 60 percent of all homes, U.S. households represent the terminus of the fracking pipeline. As of 2020, an estimated 45 percent of U.S. homes used gas-fired furnaces and boilers for home heating, and 38 percent of U.S. homes used gas-fired stoves and ovens for cooking.[443]

Combustion of methane by residential gas appliances creates nitrogen dioxide (a corrosive respiratory irritant linked to airway inflammation and asthma), carbon monoxide (a poisonous

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[438] Jan Gorski, Tahra Jutt, and Karen Tam Wu, "Carbon Intensity of Blue Hydrogen Production" (Pembina Institute, August 2021), https://www.pembina.org/reports/carbon-intensity-of-blue-hydrogen-revised.pdf.
[439] Robert W. Howarth and Mark Z. Jacobson, "How Green Is Blue Hydrogen?," *Energy Science & Engineering* 9, no. 10 (October 2021): 1676–87, https://doi.org/10.1002/ese3.956.
[440] Thomas Longden et al., "'Clean' Hydrogen? – Comparing the Emissions and Costs of Fossil Fuel versus Renewable Electricity Based Hydrogen," *Applied Energy* 306 (2022): 118145, https://doi.org/10.1016/j.apenergy.2021.118145.
[441] "Letter from Scientists, Academics, and Energy System Modellers: Prevent Proposed CCUS Investment Tax Credit from Becoming a Fossil Fuel Subsidy," January 19, 2022, https://cehoicka.lab.yorku.ca/files/2022/01/Letter-from-Academics-re-CCUS-tax-investment-credit_January-2022-4.pdf?x98920.
[442] Howard J. Herzog, "Scaling up Carbon Dioxide Capture and Storage: From Megatons to Gigatons," *Energy Economics* 33, no. 4 (July 2011): 597–604, https://doi.org/10.1016/j.eneco.2010.11.004.
[443] U.S. Energy Information Administration, "2020 RECS Survey Data," Residential Energy Consumption Survey (RECS), 2020, https://www.eia.gov/consumption/residential/data/2020/.

gas that displaces oxygen), and the carcinogens formaldehyde and benzene. All are invisible gases that form within gas flames. Gas appliances also emit unburned methane directly into indoor air through leaks and incomplete combustion. As reported by a 2022 study, three-quarters of the methane emissions from gas stoves take place when the appliance is turned off and not in use. Methane emissions from all gas stoves in U.S. homes have a climate impact comparable to the annual carbon dioxide emissions of 500,000 cars. (See footnote 2247.)

Whereas gas-fired furnaces, boilers, clothes dryers, and water heaters typically exhaust combustion byproducts to outside air as required by building codes, gas stoves represent a singular risk to public health because they more often release hazardous pollutants directly into indoor air within the living space of homes. Venting these emissions via range hoods is, by itself, an insufficient mitigation strategy. (See footnote 2251.) Many range hoods are ductless, recirculating fumes back into indoor air space rather than venting to the outside, and do little to lower exposures. Further, significant reductions in nitrogen dioxide concentrations with use of ventilation hoods are limited to cooking events done on the back burners.[444, 445]

The air inside homes with gas stoves has average concentrations of nitrogen dioxide that are 50 to 400 percent higher than the air inside homes with electric stoves.[446] These levels of air pollution can easily exceed health guidelines and would be considered illegal outdoors—as, example, along a busy roadway—where concentrations are regulated by the U.S. Environmental Protection Agency. Similarly, as documented by an August 2023 study of Colorado and California homes, gas stoves release carcinogenic benzene into kitchens at levels that exceed health guidelines. These vapors quickly spread throughout homes, in some cases raising bedroom benzene concentrations above accepted health benchmarks for hours after the stove is turned off.[447]

The link between gas stove emissions and respiratory distress in children is supported by dozens of studies dating back to 1977. By 1994, all studies of nitrogen dioxide exposure and respiratory illnesses in children showed positive associations.[448] Since then, dozens of studies have documented links between nitrogen dioxide exposure and asthmatic symptoms. Nitrogen dioxide exposure is also linked to chronic obstructive pulmonary disease and respiratory distress among those not suffering from asthma. The mechanism behind nitrogen dioxide's ability to harm the respiratory system is well-understood. Because they are not very water-soluble, nitrogen dioxide molecules, when inhaled, are bypassed by the mucus membranes in nasal and throat passages, traveling easily to the terminal bronchioles deep inside the lungs where they convert to

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[444] Nate Seltenrich, "Take Care in the Kitchen: Avoiding Cooking-Related Pollutants," *Environmental Health Perspectives* 122, no. 6 (June 2014), https://doi.org/10.1289/ehp.122-A154.
[445] Laura M Paulin, Jonathan M Samet, and Mary B Rice, "Gas Stoves and Respiratory Health: Decades of Data, but Not Enough Progress," *Annals of the American Thoracic Society*, September 13, 2023, AnnalsATS.202306-533VP, https://doi.org/10.1513/AnnalsATS.202306-533VP.
[446] U.S. Environmental Protection Agency, "Integrated Science Assessment (ISA) for Oxides of Nitrogen – Health Criteria," Final Report (Washington, D.C., July 2008), https://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=194645.
[447] Yannai S. Kashtan et al., "Gas and Propane Combustion from Stoves Emits Benzene and Increases Indoor Air Pollution," *Environmental Science & Technology*, June 15, 2023, acs.est.2c09289, https://doi.org/10.1021/acs.est.2c09289.
[448] W.Michael Alberts, "Indoor Air Pollution: NO, NO2, CO, and CO2," *Journal of Allergy and Clinical Immunology* 94, no. 2 (August 1994): 289–95, https://doi.org/10.1053/ai.1994.v94.a56007.

molecules of nitric acid. Highly reactive, these molecules trigger inflammation and acute injury to pulmonary cells. They also disable the immune cells that inhabit this tissue, increasing vulnerability to respiratory pathogens, such as influenza viruses, and so increasing susceptibility to infection. They also trigger bronchial spasms and wheezing.[449]

A 2013 systematic review and meta-analysis found that children living in homes with gas stoves have a 42 percent increased risk of having current asthma and a 24 percent increased risk of developing asthma during their lifetime. (See footnote 2253.) Using these data, a 2022 study estimated that 13 percent of childhood asthma in the United States—647,700 cases—is attributable to the use of gas stoves. The study shows that, at a population level, the asthma risk to children from gas stoves is similar to children exposed to secondhand tobacco smoke. (See footnote 2242.)

Nitrogen dioxide exposure from gas stove emissions is an environmental justice issue. Asthma is the leading chronic disease among U.S. children with Black children nearly three times more likely to suffer asthma than white children. Evidence suggests that communities of color and low-income communities are disproportionately harmed by gas stove emissions especially among households with smaller, older, less-ventilated living spaces, especially if they rely on gas ovens for supplemental heat. Despite this evidence and decades of data linking gas stoves to respiratory harm, emissions from gas stoves and other gas-burning home appliances are essentially unregulated by federal or state policies.

Both the American Medical Association and the American Public Health Association have recognized the links among gas stoves, nitrogen dioxide pollution, and increased respiratory illnesses in children and have called for a transition away from gas stoves and toward electrification of home appliances. (See footnotes 2243, 2245, 2246.)

In response to the mounting evidence that fossil fuel combustion inside of buildings is contributing significantly to the climate crisis, a growing movement of U.S. cities, counties, and states have passed, or are pursuing, building electrification measures. In response, the fossil fuel industry has mounted attacks on these efforts that include pre-emptive state legislation to block municipal ordinances. Nevertheless, a September 2023 report found that that building electrification measures that require new construction to be all-electric and prohibit gas-burning appliances would have a large impact on reducing emissions from the nation's future housing stock. The report found that passing policies that require electrification on all new residential construction, were they implemented in just 63 strategically chosen metropolitan areas, could eliminate more than half (53 percent) of methane emissions from U.S. residential buildings constructed between 2023 and 2030.[450]

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[449] Daniela Fecht et al., "Exposure to Elevated Nitrogen Dioxide Concentrations and Cardiac Remodeling in Patients With Dilated Cardiomyopathy," *Journal of Cardiac Failure* 28, no. 6 (June 2022): 924–34, https://doi.org/10.1016/j.cardfail.2021.11.023.

[450] Devyani Singh, Nathan Taft, and John Qua, "A Roadmap to Fossil-Free Homes: Where Local Building Electrification Policies Would Have the Greatest Impact" (Stand.earth Research Group, Safe Cities, Lead Locally, September 2023), https://www.safecities.earth/wp-content/uploads/2023/09/SAFE-Lead-Locally-Electrification-Report-Digital.pdf.

Case study: Drilling and Fracking in California

Undergoing a long-term decline in its oil industry, California has fallen from the nation's third-most prolific oil-producing state to seventh over the past five years. New drilling permits have steadily declined in California since 2019. In 2023, California effectively halted approvals for new wells in the state, issuing only seven permits during the first half of the year as compared to more than 200 by the same time in 2022.[451]

Fracking continues to be practiced in ten California counties, most notably in Kern County where half of all oil wells are fracked. In April 2021, a bill (SB 467) that would have banned fracking in the state by 2023 and instituted mandatory setback distances between drilling sites and residences failed to pass the state legislature. Also in April 2021, California Governor Gavin Newsom announced a plan to stop issuing new fracking permits in the state by 2024 as part of a larger proposal to phase out all oil extraction in the state by 2045.[452] By November 2021, ahead of the 2024 ban, California had already denied 109 fracking permits.[453]

Hydraulic fracturing in California is practiced differently than in other states, making its risks different. Wells are more likely to be vertical rather than horizontal, and the oil-containing rock layer is shallower. Hence, much less water is used per well for fracking as compared to other states. However, the fracking fluid used is much more chemically concentrated, the fracking zones are located closer to overlying aquifers, and the risk of a fracture reaching groundwater is higher. Furthermore, although fracking in California requires considerably less water per well, it takes place disproportionately in areas of prolonged, severe water shortages and can compete with municipal and agricultural needs for freshwater.

California is the only state that allows wastewater from oil fields to be held in unlined open pits, which creates risks for both air and groundwater contamination. Evaporation from wastewater pits is a significant source of toxic air pollution in California's San Joaquin Valley. These emissions include the volatile organic compounds benzene, toluene, ethylbenzene, and xylene, all of which are neurological toxicants. Benzene is a known cause of leukemia.

The results of a 2020 investigation showed that evaporation of these four toxic chemicals from oil and gas waste pits alone represented up to two percent of the air basin's inventory of these substances. (See footnote 398.) As of July 2018, 1,086 such pits were operational in the Central Valley, with the vast majority in Kern County. An investigation by reporters for NBC Bay Area

[451] Nichola Groom, "California New Oil Well Approvals Have Nearly Ground to a Halt," *Reuters*, July 13, 2023, https://www.reuters.com/business/energy/california-new-oil-well-approvals-have-nearly-ground-halt-data-show-2023-07-13/.
[452] Emma Bowman, "California Governor Moves To Ban Fracking By 2024," NPR.org, April 23, 2021, https://www.npr.org/2021/04/23/990368418/california-governor-moves-to-ban-fracking-by-2024.
[453] Dustin Gardiner and J.D. Morris, "Citing Climate Risks, California Is Denying Fracking Permits in Droves," *San Francisco Chronicle*, November 23, 2021, https://www.sfchronicle.com/politics/article/Citing-climate-risks-California-is-denying-16643010.php.

found additional pits not on the state's official list. In at least two instances, toxic wastewater from the pits had migrated underground for more than a mile.[454]

In 2019, a U.S. Geological Survey team working within the San Joaquin Valley in Kern County documented aquifer contamination from the downward migration of fluids stored in unlined wastewater pits as well as from the outward migration of fluids from underground disposal wells. Contamination of groundwater from disposal wells was detectable as far away as one-third of a mile (1800 feet) away. (See footnote 683.)

Similarly, a 2021 study documented contamination of groundwater resources from unlined wastewater pits throughout the southern Tulare Basin region of the San Joaquin Valley, which is also the nation's most productive agricultural region with groundwater widely used for irrigation. In one case, the carcinogen benzene was found in groundwater underlying waste pits at levels 45 times higher than the safety limit for drinking water. However, regulators concluded that remediation costs would be prohibitive.[455, 456]

In 2014, the discovery that companies had, for years, been wrongly allowed to inject oil and gas waste directly into California's freshwater aquifers led to the closing of 175 disposal wells. Impacts on drinking water are unknown. (See footnotes 742, 743.) Nevertheless, throughout 2020 and into 2021, the state issued more than 300 permits to oil and gas companies for new underground injection wells.[457]

Most fracking operations in California have taken place in areas with a long history of oil extraction. A high density of old and abandoned wells provides potential leakage pathways, should fractures intersect with them. The state's current system to prevent operators from walking away from aging wells—those both fractured and unfractured—requires that producers put up bonds to secure clean-up. However, the amounts of the bond are typically far less than the actual costs of plugging and remediating old wells. This problem has been exacerbated by the recent downturn in oil production in the state. As oil majors sell off their California assets to smaller companies, waves of bankruptcies have left clean-up costs—estimated at $500 million—to the state. In September 2023, the California legislature passed the Orphaned Well Prevention Act which, if signed by the governor, would prohibit the sale of an oil well unless the new owner can pay to plug it. An estimated 5,540 old oil wells in California are currently orphaned, with no financially solvent operator to assume the task of remediation. The new measure will not pay for remediating these wells, but it it intended to prevent the orphaning of additional 70,000 wells

[454] Stephen Stock et al., "Toxic Wastewater from Oil Fields Endangers California's Water Supply, Scientists Tell NBC Bay Area," NBC Bay Area, November 27, 2018, https://www.nbcbayarea.com/investigations/Toxic-WasteWater-From-Oil-Fields-Endangers-Californias-Water-Supply-Scientists-Tell-NBC-Bay-Area-483089841.html.
[455] Dominic C. DiGiulio et al., "Vulnerability of Groundwater Resources Underlying Unlined Produced Water Ponds in the Tulare Basin of the San Joaquin Valley, California," *Environmental Science & Technology* 55, no. 21 (November 2, 2021): 14782–94, https://doi.org/10.1021/acs.est.1c02056.
[456] Liza Gross, "Unchecked Oil and Gas Wastewater Threatens California Groundwater," *Inside Climate News*, October 24, 2021, https://insideclimatenews.org/news/24102021/california-oil-wastewater-produced-water-drought-groundwater-contamination/.
[457] Aaron Cantu, "California Is Greenlighting Oil Wells Linked to Groundwater Pollution," *Capital & Main*, April 8, 2021, https://capitalandmain.com/california-is-greenlighting-oil-wells-linked-to-groundwater-pollution-0408.

that are currently identified as idle or marginal.[458]

The combination of ongoing drought and lack of disposal options has resulted in the diversion of fracking wastewater to farmers for irrigation of crops, raising concerns about contaminated water potentially affecting food crops and draining into groundwater. Investigative reports in 2015 revealed that Chevron Corporation piped 21 million gallons of recycled oil and gas wastewater per day to farmers for crop irrigation. Tests showed the presence of several volatile organic compounds, including acetone, which is linked in lab studies to kidney, liver, and nerve damage. (See footnotes 1651-1653.)

These activities project fracking's impacts onto geographically distant populations, especially in cases where wastewater is used in crop irrigation and livestock watering. Kern County, for example, the epicenter of fracking in California, is also the world's leading producer of almonds and pistachios. Food is a troubling possible exposure route to fracking chemicals, in part because so little is known about these chemicals. According to a hazard assessment of chemicals used in California oil drilling operations that reuse wastewater for livestock watering and other agricultural purposes, more than one-third of the 173 chemicals used are classified as trade secrets: Their identities are entirely unknown. Of the remainder, ten are likely carcinogens, 22 are toxic air contaminants, and 14 had no toxicity data available. Estimating risks to consumers of the food produced with wastewater irrigation is thus not possible. (See footnote 1646.)

In fall 2021, the Central Valley Regional Water Quality Control Board assured the public that eating California crops grown with oil field wastewater "creates no identifiable increased health risks" based on the results of a study conducted by oil industry consultants.[459] The Board's own expert panel, however, conceded that the data gaps in the analysis left "potentially significant unknowns" about the chemicals in question and concluded that the investigation did not answer fundamental safety questions about irrigating crops with wastewater from drilling operations. More than 60 percent of chemicals identified in the study as most likely to pose risks to human health lacked both toxicity information and approved testing methods.[460]

The other area in California where fracking is concentrated, the Los Angeles Basin, is located directly under the most populous county in the United States. As of 2022, there were a total of 7,174 operational oil and gas wells in Los Angeles County; 3,577 were active and 3,597 idle. "Unincorporated" areas of the county include 1,683 wells; 997 of those were active and 686 were idle. Of the 2,062 wells located in the City of Los Angeles, 725 were active and 1,337 were idle. Another city within the county, Culver City, includes a portion of the Inglewood Oil field, one of the largest urban drilling areas in the country, though the majority of the field's wells are located in unincorporated areas.[461]

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[458] Plachta, "Lawmakers Want to Put Oil Industry on the Hook to Plug Old Wells. Will Gavin Newsom Sign It?"
[459] Carolyn M. Cooper et al., "Oil and Gas Produced Water Reuse: Opportunities, Treatment Needs, and Challenges," *ACS ES&T Engineering*, 2021, acsestengg.1c00248, https://doi.org/10.1021/acsestengg.1c00248.
[460] Liza Gross, "A California Water Board Assures the Public That Oil Wastewater Is Safe for Irrigation, But Experts Say the Evidence Is Scant," *Inside Climate News*, February 6, 2022, https://insideclimatenews.org/news/06022022/a-california-water-board-assures-the-public-that-oil-wastewater-is-safe-for-irrigation-but-experts-say-the-evidence-is-scant/.
[461] Kyle Ferrar, "Personal Correspondence" (Western Program Coordinator, FracTracker Alliance, February 25, 2022).

At least 1.7 million people in Los Angeles live or work within one mile of an active oil or gas well, and 600,000 live within a half mile. A 2017 study shows that many of the same chemicals used to stimulate wells during fracking operations are also used in urban oil wells located in densely populated areas of southern California. (See footnote 748.) A 2021 study that deployed air quality monitors in Los Angeles neighborhoods where oil and gas drilling take place found methane spikes near wells and an associated pipeline. A second study found that ambient air levels of methane—along with benzene, toluene, styrene, ethane, propane and other volatile compounds—were highly elevated during operations and fell when wells were subsequently idled. (See footnote 494.)

Air pollutants from urban oil and gas operations disproportionately affect the city's Black and Latino residents. (See footnote 349.) A July 2023 study found that oil and gas facilities in Los Angeles County are operating in neighborhoods already cumulatively burdened with other polluting industries and with higher proportions of Black residents.[462] An August 2023 study found that living near urban drilling sites in Los Angeles is significantly associated with higher blood pressure.[463]

In December 2020, after a lengthy legal analysis, the Los Angeles City Council environment committee voted unanimously to support a proposal to outlaw all oil drilling within the city limits via updates to zoning codes that would make oil and gas extraction "nonconforming land use" across Los Angeles.[464] In January 2022, the motion was unanimously passed by the full Council, which voted to ban all new oil and gas wells and phase out the more than 2,000 existing ones. In the interim, the Los Angeles County Board of Supervisors unanimously voted to phase out oil and gas drilling and to ban new drilling within the county's unincorporated areas, on a schedule to be determined, and Culver City unanimously voted to prohibit the drilling of any new, or redrilling of any existing, wells, and to require the phasing out, plugging, and restoration of all existing wells by November 24, 2026.

At this writing, California, remains the only oil- or gas-producing state that does not limit how close to residences or schools drilling and fracking activities may be conducted. (Pennsylvania requires a 500-foot setback distance, for example, while Colorado requires 2,000 feet.) In September 2022, Governor Newsom issued regulations that would prohibit new drilling within 3,200 feet (one kilometer) of homes, schools, hospitals, and nursing homes and increasing monitoring requirements for pre-existing wells within the buffer zone. The setback rule was to

[462] Marissa Chan, Bhavna Shamasunder, and Jill E. Johnston, "Social and Environmental Stressors of Urban Oil and Gas Facilities in Los Angeles County, California, 2020," *American Journal of Public Health*, July 27, 2023, https://doi.org/10.2105/AJPH.2023.307360.
[463] Jill E. Johnston et al., "Cardiovascular Health and Proximity to Urban Oil Drilling in Los Angeles, California," *Journal of Exposure Science & Environmental Epidemiology*, August 8, 2023, https://doi.org/10.1038/s41370-023-00589-z.
[464] Nathan Solis, "Los Angeles Moves Closer to Forcing Oil & Gas Drillers out of City," Courthouse News Service, December 1, 2020, https://www.courthousenews.com/los-angeles-moves-closer-to-forcing-oil-gas-drillers-out-of-city/.

have gone into effect in January 2023.[465, 466] However, its implementation was suspended when the state qualified an oil industry-back ballot referendum that will put the setback rule (California Senate Bill 1137) before a public vote in November 2024.[467, 468]

The Los Angeles basin is the second most important urban carbon-emitting region in the United States, with most of the excess methane emissions attributable to leaks from the natural gas system. Legislation passed in 2014 requires reductions in fugitive emissions from transmission and distribution pipelines carrying natural gas. However, a 2023 study using remote sensing found that the decade-long decrease in methane leaks is smaller than previously believed based on self-reported measurements.[469]

Case Study: Drilling and Fracking in Florida

Gas and oil drilling in Florida, now only a minor industry, is currently concentrated in two areas: the western Panhandle near Pensacola and the Everglades area of southwest Florida. So far, fracking has been used at least once—in 2013 at a test well located in the Corkscrew Swamp Sanctuary near Naples in Collier County. The Texas company that fracked this well, using high-pressure acid fracturing techniques to dissolve the bedrock, received a cease-and-desist order from the Florida Department of Environmental Protection.[470]

Florida is heavily dependent on natural gas, which provides 70 percent of the electricity generated in its power plants. Renewed interest in oil and gas exploration in Florida has prompted public debate about fracking and whether to promulgate state regulations or prohibit it outright, possibly including a ban on the use of the rock-dissolving technology called matrix acidizing in addition to hydraulic fracturing *per se.* Bills that sought to ban fracking but not acidizing failed to pass in the Florida legislature in the 2019 legislative session.[471] In November

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[465] Aaron Cantu, "California Oil Safety Rule Contains 'Zombie Well' Loophole, Advocates Say," *Capital & Main*, February 17, 2022, https://capitalandmain.com/california-oil-safety-rule-contains-zombie-well-loophole-advocates-say.

[466] Hilary Beaumont, "Will California's New Oil and Gas Laws Protect People from Toxic Pollution?," *Environmental Health News*, January 9, 2023, https://www.ehn.org/oil-and-gas-pollution-california-2659059703.html.

[467] Vania Patino, "Oil Well Setback Law on Hold Pending 2024 Voter Referendum," *23 ABC Bakersfield*, February 6, 2023, https://www.turnto23.com/news/state/oil-well-setback-law-on-hold-pending-2024-voter-referendum.

[468] Liza Gross, "Q&A: California Drilling Setback Law Suspended by Oil Industry Ballot Maneuver. The Law's Author Won't Back Down," *Inside Climate News*, February 6, 2023, https://insideclimatenews.org/news/06022023/california-drilling-setback-lena-gonzalez/.

[469] Zhao-Cheng Zeng et al., "Decadal Decrease in Los Angeles Methane Emissions Is Much Smaller than Bottom-up Estimates," *Nature Communications* 14, no. 1 (September 2, 2023): 5353, https://doi.org/10.1038/s41467-023-40964-w.

[470] "Could Leftover Wastewater from Balky Oil Well End up a Health Hazard?," *Naples Daily News*, January 1, 2015, http://archive.naplesnews.com/news/local/could-leftover-wastewater-from-balky-oil-well-end-up-a-health-hazard-ep-853723380-335781721.html/.

[471] Samantha J. Gross, "Environmentalists Cite Report on Florida Oil Spills as Bid to Ban Fracking Stalls," *Miami Herald*, April 17, 2019, sec. Environment, https://www.miamiherald.com/news/local/environment/article229355974.html.

2019, a bill to ban both hydraulic fracturing and matrix acidization (SB 200) passed a Florida Senate committee but failed to pass in the 2020 legislative session.[472] A fracking ban proposal (SB 546) that included matrix acidization also failed in the spring 2021 legislative session, as did a bill (SB722) that would have banned oil and gas drilling within the Everglades Protection Area.[473]

In spite of the failure of fracking ban bills to pass the Florida state legislature, drilling and fracking in the state has been thwarted by other efforts. In May 2020, the state of Florida purchased a 20,000-acre tract of land in the Everglades to prevent the family who owned it from drilling for oil. The owners had won a legal battle that allowed them to secure permits for an exploratory well.[474, 475] In November 2021, the Florida Department of Environmental Protection denied an exploratory drilling permit in Immokalee, one of the nation's leading tomato-growing regions and part of the Big Cypress watershed.[476] In March 2023 an administrative law judge upheld that decision.[477]

In June 2021, Florida governor Ron DeSantis signed into law a bill (SB 1128/HB119) that invalidates local comprehensive plans that restrict natural gas use or otherwise pursue 100 percent renewable energy initiatives. An earlier version of the bill would have also preempted municipalities from enacting local fracking bans. As amended, it does not.[478]

Florida has more available groundwater than any other state; it is the drinking water source for 93 percent of Florida's population. Groundwater is also pumped to irrigate crops and provide frost protection to winter crops. Most of this water is held in the Floridan Aquifer, which extends across the entire peninsula and into parts of Georgia, Alabama, and South Carolina. This aquifer provides drinking water to ten million people in both rural and urban communities, including residents of several major cities: Gainesville, Jacksonville, Orlando, Tallahassee, and Tampa. Overlain by smaller, shallower aquifers in southern Florida, it is a highly permeable, highly interconnected subterranean system, with water moving rapidly in multiple directions through massive shelves of limestone, which represent the dissolved shells and fossilized skeletons of prehistoric marine organisms. Honeycombed with pores, fissures, joints, and caves, the

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[472] Jim Turner, "Florida Fracking Ban Could Run into Roadblocks," *Pensacola News Journal*, November 5, 2019, sec. News, https://www.pnj.com/story/news/2019/11/05/florida-fracking-ban-could-run-into-roadblocks/4163695002/.
[473] "SB 546: Well Stimulation," The Florida Senate, April 30, 2021, https://www.flsenate.gov/Session/Bill/2021/546.
[474] Alex Harris, "Florida Plans to Buy and Protect Everglades Land in Broward Targeted for Oil Drilling," *Miami Herald*, January 15, 2020, sec. Environment, https://www.miamiherald.com/news/local/environment/article239311568.html#:~:text=Ron%20DeSantis%20announced%20Wednesday.,land%20acquisition%20in%20a%20decade.
[475] David Fleshler, "Land Purchase Finalized to Prevent Everglades Oil Drilling," *Sun Sentinel*, May 5, 2020, sec. Local News, https://www.sun-sentinel.com/local/broward/fl-ne-everglades-oil-drilling-deal-20200505-a2aq232m35h4ngx2gt2vlphv5m-story.html.
[476] Karl Schneider, "State Denies Oil Drilling Permit in Immokalee, Fried Calls for End to State Permits," *Naples Daily News*, November 8, 2021, https://www.naplesnews.com/story/news/environment/2021/11/08/fdep-denies-oil-drilling-permit-immokalee-nikki-fried-calls-end-state-permits/6337066001/.
[477] Staff, "Judge Rules against Oil Drilling Plan in Florida's Big Cypress," *88.5 WMNF*, March 29, 2023, https://www.wmnf.org/judge-rules-against-oil-drilling-plan-in-floridas-big-cypress/.
[478] Florida House of Representatives, "366.032 Preemption over Utility Service Restrictions.," n.d., https://www.flsenate.gov/Session/Bill/2021/919/BillText/er/PDF.

underground terrain of the Floridan Aquifer resembles a vast, brittle, sponge partly covered with sand and clay. Springs and sinkholes are common.[479, 480]

It is not known whether fracking in Florida could induce sinkholes to open up or whether alterations in underground pressures could cause springs to go dry. Certainly, Florida's porous geology makes it vulnerable to groundwater contamination. Crumbly, soluble limestone offers pathways for contaminants spilled on the surface to travel deep into the aquifer, where they can be dispersed over great distances by the aquifer's river-like currents. A 2003 experiment with a dye tracer showed the special susceptibility of Florida's groundwater to potential contamination; within a few hours, the red dye traveled through the aquifer a distance (330 feet) that researchers had presumed would take days.[481]

Compounding these risks, Florida's exposure to hurricanes makes it vulnerable to spills of fracking-related chemicals. In August 2017, flooding from Hurricane Harvey shut down fracking sites in Texas and triggered 31 separate spills at wells, storage tanks, and pipelines. (See footnotes 1582-1584.)

It is unclear where Florida would send any potential fracking wastewater for treatment and/or for underground injection. Florida currently injects other types of liquid waste into disposal wells that are located above, rather than below, oil- and gas-producing zones. The injection of fracking waste in these same shallower layers may make earthquakes less likely than, for example, in Oklahoma (where it is injected into deep formations), but it would also locate that waste closer to the aquifers, which are poorly mapped. To undertake the necessary study to determine how securely Florida's geological formations could contain wastewater from drilling and fracking operations and protect drinking water would be, in the words of two geophysicists, "a monumental task requiring full-time work…for decades."[482] There are reasons to be concerned. In South Florida in the 1990s, 20 stringently regulated disposal wells failed and leaked sewage waste into the Upper Floridan Aquifer, a potential future source of drinking water for Miami.[483]

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[479] Richard H. Johnston and Peter W. Bush, "Summary of the Hydrology of the Floridan Aquifer System in Florida and in Parts of Georgia, South Carolina, and Alabama," September 4, 2013, https://pubs.er.usgs.gov/publication/pp1403A.

[480] Ann B. Tihansky and Lari A. Knochenmus, "Karst Features and Hydrogeology in West-Central Florida—a Field Perspective" (U.S. Geological Survey, February 13, 2001), http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.565.2989&rep=rep1&type=pdf.

[481] Wellfield Technical Work Group, "Report of the Miami-Dade County Wellfield Technical Workgroup" (Miami-Dade County Department of Regulatory and Economic Resources, July 2017), https://ecmrer.miamidade.gov/reports/WellfieldTechnicalWorkgroupReportJuly2017.pdf.

[482] Ray Russo and Elizabeth Screaton, "Should Florida 'frack' Its Limestone for Oil and Gas? Two Geophysicists Weigh In," University of Florida News, May 5, 2016, http://news.ufl.edu/articles/2016/05/should-florida-frack-its-limestone-for-oil-and-gas-two-geophysicists-weigh-in.php.

[483] Abrahm Lustgarten, "Injection Wells: The Poison Beneath Us," ProPublica, June 21, 2012, https://www.propublica.org/article/injection-wells-the-poison-beneath-us.

Compilation of Studies & Findings

Air pollution

Air pollution associated with fracking and flaring is a grave concern with a range of impacts. Researchers have documented more than 200 different air pollutants near drilling and fracking operations. Of these, 61 are classified as hazardous air pollutants with known health risks, and 26 are classified as endocrine disruptors.

Areas with substantial drilling and fracking build-out show high levels of ground-level ozone (smog), striking declines in air quality, and, in several cases, increased rates of health problems with known links to air pollution. Air sampling surveys find high concentrations of fine particulate air pollutants and volatile organic compounds (VOCs), especially carcinogenic benzene and formaldehyde, both at the wellhead and at distances that exceed legal setback distances from wellhead to residence. In some cases, VOC concentrations exceeded federal safety standards by several orders of magnitude.

Researchers in Colorado have documented that air pollution increased with proximity to drilling and fracking operations and was sufficiently high to raise cancer risks in some cases. In Colorado's Front Range, nitrogen dioxide emissions from drilling and fracking operations now exceed levels produced by all the region's cars and trucks. In Pennsylvania, a 2023 study documented significant increases in fine particulate matter in ambient air near fracking wells. In California, oil and gas wells increase the exposure of nearby residents to levels of air pollution sufficient to harm health with elevated ozone levels up to 2.5 miles away.

Exposure to emissions from natural gas flares and diesel exhaust from the 4,000-6,000 truck trips per well pad also pose respiratory health risks for those living near drilling operations. The United States leads the world in the number of flare stacks. Air pollutants from flaring operations include VOCs, polycyclic aromatic hydrocarbons, carbon monoxide, toxic heavy metals, formaldehyde, and soot. In North Dakota, rates of hospitalization for respiratory distress are linked to the intensity of flaring activity, with effects seen in people living up to 60 miles away.

Evidence implicates U.S. shale gas extraction in the global spike in atmospheric ethane and propane. Drilling and fracking operations in North Dakota's Bakken oil and gas field alone contribute two percent of global ethane emissions and directly impact air quality across North America. Like methane, ethane is both a greenhouse gas and a precursor for ozone formation.

A 2021 Harvard study found that, in at least 19 states, burning gas to generate electricity now kills more people from air pollution than coal due to exposure to the fine particulate matter air pollution (PM2.5) that is generated when gas is burned.

- May 8, 2023 – An interdisciplinary research team assessed the public health impacts and full cycle costs of air pollution from oil and gas extraction in the United States by using geospatially resolved emissions data and simulating the consequential exposures to ozone, fine particulate matter, and nitrogen oxides. The results showed that, in 2016, air pollution from the oil and gas sector was responsible for an estimated 410,000 asthma exacerbations, 2,200 new cases of childhood asthma and 7,500 excess deaths. These outcomes represent an estimated $77 billion in total health impacts. Of the three types of oil- and gas-derived air pollution, nitrogen dioxide was the highest contributor to health harm (37%) followed by ozone (35%) and fine particulate matter (28%). The research team also compared these health costs to the climate costs caused by methane emissions. When monetized, the collective air quality health impacts of oil and gas production exceeded estimated climate impact costs from methane leakage by a factor of three.[484]

- March 6, 2023 – Using satellite-based measurements and an atmospheric dispersion model, an assessment of the air quality impacts of fracking in Pennsylvania between 2000 and 2018 identified significant increases in fine particulate matter in ambient air in the vicinity of more than 20,000 gas wells. The research team found that deterioration of air quality was highest during the well preparation and drilling stage followed by the first three years a shale gas well goes into production. Mortality analysis estimates that the exposure to this air pollution resulted in 20 additional deaths in communities across 40 Pennsylvania counties with a total population of 840,000. "Our estimates provide robust evidence that shale gas development is increasing [fine particulate matter] in the vicinity of fracked wells, providing new evidence on the mechanism underlying…prior health studies."[485]

- February 10, 2023 – A research team led by the Colorado School of Mines undertook a critical review of third-party natural gas certification criteria in the United States that label certain gas deliveries as "green" or "responsibly sourced." Certification programs primarily focus on the issue of methane emissions. Other externalities include local air and water pollution, noise and light pollution, and health impacts, which are accounted for in some, but not all, certification programs. The team found that measuring and verifying fugitive methane emissions throughout the supply chain is costly and introduces significant uncertainty. Furthermore, the ability of regulatory bodies to enforce rapid curtailment of methane emissions is constrained by "the private ownership of relevant data, the global nature of the issue, and [the need to preserve] the overall competitiveness of the industry."[486]

- December 13, 2022 – The state of Colorado gave notice that it had miscalculated nitrogen oxide emissions from drilling and fracking operations in the state, which will require it to update its emissions inventory. Nitrogen oxides are precursors of ground-level ozone,

[484] Buonocore et al., "Air Pollution and Health Impacts of Oil & Gas Production in the United States."
[485] Ruohao Zhang et al., "Air Quality Impacts of Shale Gas Development in Pennsylvania," *Journal of the Association of Environmental and Resource Economists* 10, no. 2 (March 1, 2023): 447–86, https://doi.org/10.1086/721430.
[486] Sankalp Garg et al., "A Critical Review of Natural Gas Emissions Certification in the United States," *Environmental Research Letters* 18, no. 2 (February 1, 2023): 023002, https://doi.org/10.1088/1748-9326/acb4af.

also known as smog. Specifically, the Air Pollution Control Division of the Colorado Department of Public Health and Environment announced that it was withdrawing parts of its Severe State Implementation Plan in light of this error, which underestimates the true burden of nitrogen oxide emissions from the oil and gas industry in Colorado's Front Range. In fact, the levels of created by drilling and fracking operations are twice as high as the levels originally stated in the Implementation Plan and far higher than the levels of smog produced by all the region's cars and trucks. Providing a framework for improving air quality in Colorado's Front Range, the Implementation Plan is required under the federal Clean Air Act because Colorado is out of compliance with national air quality standards.[487]

- November 1, 2022 – Located adjacent to the intensely fracked Permian Basin, Carlsbad Caverns National Park in southeastern New Mexico suffers from haze caused by air pollution. Collecting field measurements of fine particles, aerosols, and trace, a research team conducted an air quality study in the park in summer 2019. Findings showed that contributors to visible air pollution include sulfate, soil dust (often reacted by nitric acid), methane, and black carbon. The highest concentrations of air pollutants and the worst period of visibility corresponded with periods of air blowing in from the Permian Basin.[488]

- October 27, 2022 – A British team of researchers investigated the air pollution generated during the preparatory, pre-operational stage of hydraulic fracturing, a prolonged and largely overlooked phase of shale gas development. While fracking itself typically requires only three to five days, the preparatory phase takes place over a period of weeks or months. During this time, large amounts of heavy machinery and infrastructure are delivered to the site, the well pad is built, and the rig transported. The pre-operational stage of the fracking process is characterized by a spike in heavy-duty vehicle traffic. The results of this study show that pre-operational activities cause total nitrogen oxides emissions to soar by 274 percent. Combustion-related sources were mainly responsible for this spike in air pollution, which was dominated by nitrogen oxide (NO). The authors recommend that, going forward, the pre-operational, preparatory stage of fracking operations be included in environmental assessments of shale gas extraction.[489]

- April 1, 2022 – A research team working in North Dakota documented a correlation between hospitalizations for respiratory distress increase and flaring activity, with effects seen in people living up to 60 miles away. Over the years 2007-2015, for each 1 percent increase in the amount of flared gas, the downwind respiratory-related hospitalization visitation rate increased by 0.73 percent. Furthermore, "the zip codes exposed to a disproportionate amount of flaring tend to be economically disadvantaged and

[487] The Colorado Department of Public Health and Environment, "Notice of Temporary Withdrawal of Limited Parts of the Severe State Implementation Plan," December 13, 2022, https://wp-cpr.s3.amazonaws.com/uploads/2022/11/2022-11-11-NOTICE-OF-TEMP-WITHDRAWAL-1.pdf.
[488] Lillian E. Naimie et al., "PM2.5 in Carlsbad Caverns National Park: Composition, Sources, and Visibility Impacts," *Journal of the Air & Waste Management Association* 72, no. 11 (November 2, 2022): 1201–18, https://doi.org/10.1080/10962247.2022.2081634.
[489] Shona E. Wilde et al., "The Air Quality Impacts of Pre-Operational Hydraulic Fracturing Activities," *Science of The Total Environment* 858 (February 2023): 159702, https://doi.org/10.1016/j.scitotenv.2022.159702.

communities of color."[490] These excess hospitalizations represent health care costs that could be avoided. Had the 88 percent gas capture rate established by North Dakota's recent flaring policy been in place prior to 2007, "health costs from respiratory-related hospital visits in North Dakota would be reduced by $443 million USD (in 2018 dollars) over a nine-year period. Supplementing this figure with suggestive estimates of flaring's impact on all hospitalizations, the estimated benefits of this policy increase to $853 million." These health cost estimates are likely a lower bound, the authors note, as they do not include mortality or cognitive health costs from increased air pollution.

- February 25, 2022 – A research team led by Rice University environmental engineers calculated that U.S. flaring was responsible for 26 to 53 premature deaths in 2019 from exposure to the soot-like air pollutant carbon black alone.[491]

- February 1, 2022 – An analysis of drilling sites across California based on 14 years of air monitoring data found that living near oil and gas wells increases the exposure of nearby residents to five types of air pollutants: fine particles, carbon monoxide, nitrogen dioxide, ozone, and volatile organic compounds. These effects were seen in both preproduction and production stages of extraction and at distances up to 4 kilometers (2.5 miles) from the wells, with Black and Latino communities disproportionately affected. These findings validate the approach of many other studies that use distance from wells and activity of wells as a surrogate for exposure to pollutants.[492]

- June 23, 2021 – A National Oceanic and Atmospheric Administration (NOAA) team quantified methane emissions and emissions of other volatile organic air pollutants known to create ozone (smog) from oil- and gas-producing regions across the United States. The findings showed that volatile organic compounds (VOCs) from oil and natural gas extraction have likely been underestimated by a factor of two and that oil and gas emissions represent a significant source of volatile organic compounds to the atmosphere over the United States.[493]

- May 19, 2021 – Air concentrations of methane, non-methane hydrocarbons (NMHC), benzene, toluene, ethylbenzene, xylenes, styrene, n-hexane, n-pentane, ethane, and propane decreased following the suspension of urban drilling activities in a Los Angeles, California neighborhood. A USC-led team used ambient air monitoring adjacent to the AllenCo oil and gas production site during active operations and during the following idle period, the first study of its kind. The team determined that the drilling activities contributed 23.7 percent to the total VOCs measured during the active phase, versus 0.6 percent in the idle phase. Average methane concentrations were 2.53 ppm in the active

[490] Wesley Blundell and Anatolii Kokoza, "Natural Gas Flaring, Respiratory Health, and Distributional Effects," *Journal of Public Economics* 208 (April 2022): 104601, https://doi.org/10.1016/j.jpubeco.2022.104601.
[491] Chen Chen et al., "Black Carbon Emissions and Associated Health Impacts of Gas Flaring in the United States," *Atmosphere* 13, no. 3 (February 25, 2022): 385, https://doi.org/10.3390/atmos13030385.
[492] David J.X. Gonzalez et al., "Upstream Oil and Gas Production and Ambient Air Pollution in California," *Science of The Total Environment* 806 (2022), https://doi.org/10.1016/j.scitotenv.2021.150298.
[493] Colby B. Francoeur et al., "Quantifying Methane and Ozone Precursor Emissions from Oil and Gas Production Regions across the Contiguous US," *Environmental Science & Technology* 55 (2021): 9129–39, https://doi.org/10.1021/acs.est.0c07352.

phase and 1.68 ppm in the idle phase (consistent with background averages in California), and the highest one-minute averaged real-time methane concentration was 37.54 ppm. Average NMHC concentrations also dropped from the active phase to the idle phase. Authors wrote, "the results suggests that a broad range of hazardous air pollutants are co-emitted during active operations, and these compounds may be biologically additive or act synergistically in the human body, near a vulnerable population." They note that the community near the AllenCo site "is home to over 90% people of color… and approximately three-quarters of households live below 200% of the federal poverty line," and is "among the top 10% most disproportionately-environmentally burdened in the state."[494]

- May 5, 2021 – Ethane co-occurs with methane as a volatile air pollutant released by drilling and fracking operations. While methane also has many natural sources, such as wetlands, ethane has almost none. Therefore, ethane can be used as a surrogate for estimating methane emissions from oil and gas extraction activities. Using measurements of ethane collected by aircraft in the southcentral and eastern United States, a Pennsylvania State University research team showed that methane emissions from oil and gas extraction are significantly higher than previously presumed and, indeed, consistently exceed values calculated by leak rate estimates used by the U.S. Environmental Protection Agency (EPA). The team estimated that methane emissions arising from drilling and fracking are larger than EPA inventory values by 48 to 76 percent. This study corroborates several other earlier studies, all of which raise concerns of a broad, historic underestimation of methane leakage from U.S. oil and gas operations.[495]

- May 5, 2021 – Over the last decade, the U.S. fracking boom has prompted an energy transition away from coal and toward natural gas and biomass, as gas has replaced coal in both electricity generation and industry. However, this switch has not eliminated harm to public health from air pollution. A Harvard-led team used modeling and emissions inventory data to reconstruct the changes in health impacts from particulate matter air pollution in the United States from 2008 to 2017. The results showed substantial changes in the contribution to mortality impacts from stationary sources of fine-particle ($PM_{2.5}$) air pollution. In 19 states, burning gas for electricity now kills more people from exposure to fine particles than does coal. In 2008, when coal produced nearly half the nation's electricity, power plant emissions caused between 59,000 and 66,000 premature deaths. By 2017, 10,000 to 12,000 deaths were caused by power plants. Sharp reductions in sulfur dioxide emissions, the source of which is largely electricity generation from coal, have led to a much more complex picture of contributors to particulate air pollution and to public health impacts, with many sources now contributing, all within the same order of magnitude and with transportation emissions now having a larger proportion of total air pollution health impacts. This study found that air pollution from gas, wood, and biomass were, by 2017, collectively responsible for between 29,000 and 46,000

[494] Jill E. Johnston et al., "Changes in Neighborhood Air Quality after Idling of an Urban Oil Production Site," *Environmental Science: Processes & Impacts* 23, no. 7 (2021): 967–80, https://doi.org/10.1039/D1EM00048A.
[495] Zachary R. Barkley et al., "Analysis of Oil and Gas Ethane and Methane Emissions in the Southcentral and Eastern United States Using Four Seasons of Continuous Aircraft Ethane Measurements," *JGR: Atmospheres* 126, no. 10 (2021), https://doi.org/10.1029/2020JD034194.

premature deaths. The authors emphasized that their study does not include any health impacts from exposure to ozone or nitrogen oxides or localized health impacts from hazardous air pollution emissions from fuel extraction processes or combustion. It also does not include methane leaks across the gas supply and distribution chain or health impacts of indoor exposures to gas combustion.[496] What the study does show, said lead author Jonathan Buonocore, is that "if you swap out one combustion fuel for another, that's not a pathway to a healthy energy system." As gas represents an increasing fraction of fuel burned for U.S. electricity production, it has also become increasingly responsible for a larger proportion of health harms from air pollution generated from stationary sources. [497]

- April 29, 2021 – An investigation by *Bloomberg News* revealed that two Permian basin facilities that process and purify raw natural gas were the two biggest polluters during the February 2021 cold snap in Texas, accounting for nearly one-fifth of the state's total air pollution. Gas processing plants are designed for continuous flow of gas, and power outages therefore require flaring of all incoming gas. During the prolonged winter blackouts in Texas, loss of gas supply to power plants contributed to the power outages, which, in turn, compounded operations problems at the gas processors, leading to "a complete collapse of general infrastructure." Further, as revealed in an analysis of state records, these two plants are persistent super-emitters, releasing hazardous gases above permitted levels more than 400 times since the beginning of 2019.[498]

- March 26, 2021 – Using an ambient air monitoring laboratory, a research team identified and quantified air contaminants from a fracking well pad in West Virginia from September 2015 through February 2016. The results showed a shifting profile of air pollution that was a function of the phase of well pad development. The peak concentration was observed during the drill-out stage. There was a dramatic increase in ethane and methane emissions during the flowback phase. The emission rates of benzene and other volatile organic compounds also peaked during flowback. Benzene was also high during hydraulic fracturing as was toluene, which was mainly released from motor vehicle emissions. Overall, a multivariate analysis showed that there were three potential factor profiles: natural gas, regional transport/photochemistry, and engine emissions. "This is the first study, to our knowledge, to collect high-time-resolution ambient concentrations of compounds emitted from well pad activity on Marcellus Shale during

[496] Jonathan J. Buonocore et al., "A Decade of the U.S. Energy Mix Transitioning Away from Coal: Historical Reconstruction of the Reductions in the Public Health Burden of Energy," *Environmental Research Letters* 16, no. 5 (2021), https://doi.org/10.1088/1748-9326/abe74c.
[497] Alexander C. Kaufman, "Cleaner 'Bridge' Fuels Are Killing Up to 46,000 Americans Per Year, Study Shows," *Huffington Post*, May 5, 2021, https://www.huffpost.com/entry/air-pollution-bridge-fuels_n_608c4fbde4b0ccb91c31d21a.
[498] Kevin Crowley, "Hidden Super Polluters Revealed in Wake of Texas Energy Crisis," *Bloomberg Green*, April 29, 2021, https://www.bloomberg.com/news/articles/2021-04-29/hidden-super-polluters-revealed-in-wake-of-texas-energy-crisis.

various phases of operation such that the relative air quality effect of each phase of development can be investigated."[499]

- March 11, 2021 – Satellite data shows that gas flaring at U.S. oil and gas facilities reached an all-time high in February 2021 when frigid weather conditions in Texas forced refineries, gas processing plants, and LNG terminals to release massive amounts of gas on an emergency basis in response to a collapse in the state's energy infrastructure.[500]

- March 9, 2021 – An independent analysis by three environmental organizations revealed that industrial facilities in Texas illegally released more than three million excess pounds of pollution in advance of, and during, the winter storm in February 2021. In addition, emissions increased in every major oil field in the state—the West Texas Permian Basin, South Texas' Eagle Ford Shale, and the Barnett Shale in North Texas—as drillers flared off natural gas that they could not store or transport as pipelines started to freeze.[501]

- March 3, 2021 – A research team used air quality monitors to evaluate air pollutants over a four-year period in three Los Angeles neighborhoods where oil and gas drilling takes place. They found elevated methane levels near drilling sites, including at an oil and gas facility classified as inactive. Other VOCs were also elevated in close proximity to wells and appeared related to oil and gas activity.[502]

- February 25, 2021 – Two rural communities in California's Central Valley that suffer some of the worst air pollution in the state gained negotiating power under a law that compels regional air pollution districts to share decision-making with communities. Located in the heart of the state's oil-producing region, Arvin and Lamont intend to demand stricter regulations over oil and gas extraction activities in Kern County, where 70 to 80 percent of California's oil production takes place.[503]

- February 23, 2021 – A research team from University of California, Los Angeles used satellite observations and census data to estimate the number of nightly flaring events across all fracking sites (oil shale plays) in the United States between March 2012 and February 2020. They found that 83 percent of the flaring took place in three basins—the

[499] Nur H. Orak, Matthew Reeder, and Natalie J. Pekney, "Identifying and Quantifying Source Contributions of Air Quality Contaminants During Unconventional Shale Gas Extraction," *Atmospheric Chemistry and Physics* 21 (2021): 4729–39, https://doi.org/10.5194/acp-21-4729-2021.
[500] Pippa Luck, "Rystad Energy: Gas Flaring at US Oil Refineries Reached Highest on Record," *Hydrocarbon Engineering*, March 11, 2021, https://www.hydrocarbonengineering.com/refining/11032021/rystad-energy-gas-flaring-at-us-oil-refineries-reached-highest-on-record/.
[501] Amal Ahmed, "Industrial Facilities Released Millions of Pounds of Illegal Pollution During the Winter Storm," *Texas Observer*, April 9, 2021, https://www.texasobserver.org/industrial-facilities-released-millions-of-pounds-of-illegal-pollution-during-the-winter-storm/.
[502] Kristen Okorn et al., "Characterizing Methane and Total Non-Methane Hydrocarbon Levels in Los Angeles Communities with Oil and Gas Facilities Using Air Quality Monitor," *Science of the Total Environment* 777 (2021), https://doi.org/10.1016/j.scitotenv.2021.146194.
[503] Ingrid Lobet, "Small Towns Get Ready to Fight Big Oil over Air Quality in Central Valley," *Capital & Main*, February 25, 2021, https://capitalandmain.com/small-towns-get-ready-for-big-fights-over-air-quality-in-california-heartland-0225.

Williston Basin in North Dakota, Permian Basin in west Texas, and the Western Gulf Basin in southern Texas and Louisiana—and estimated that over half a million people in these basins reside within three miles of a flare, with 39 percent of them living near more than 100 nightly flares. In these regions, Black, Indigenous, and people of color were disproportionately exposed to flaring. The research team recommended stricter regulations.[504]

- February 1, 2021 – The fracking boom in the Denver-Julesburg Basin is a significant source of air pollution, including benzene and toluene, in northeastern Colorado. Oil production in the region increased by eight-fold between 2006 and 2016, while natural gas production tripled over the same time period. An international team of researchers estimated the contribution of these pollutants to ozone creation (smog) in Plattville, a small municipality within an area of intense drilling and fracking, and compared it to the urban core of Denver. They found that vapors from condensate tanks and other fracking infrastructure dominated the source contributions in Plattville, whereas vehicular emissions have a higher contribution in Denver. The largest contributor to benzene in the ambient air of Plattville was drilling and fracking operations, whereas vehicular emissions were the largest source of benzene in Denver.[505]

- December 22, 2020 – Utah's Uinta Basin contains about 10,000 active oil and gas wells and suffers during winter months from high levels of ozone. The oil and gas industry is the major source of chemical emissions that combine to create ozone. A team from Utah State University measured the composition and distribution of ozone-forming pollutants in the basin. They found higher levels of these pollutants in areas of dense oil production than in dense gas production. Twenty-eight percent of the potential for air pollutants to create ozone was due to alkenes in areas with dense oil production. The most likely source of these air pollutants was natural gas-fueled engines in the oil-producing regions, especially artificial lift engines, which are commonly used at oil wells but not at natural gas wells.[506]

- November 9, 2020 – Using a U.S. Department of Energy mobile air-monitoring laboratory, researchers collected ambient air monitoring data from two fracking sites in Pennsylvania and six in West Virginia throughout the production lifecycle—from well-pad construction through drilling, fracturing, flowback, and completion. The objective of this study was to analyze the air pollutants from the various upstream stages of shale gas production and develop a predictive model. The results showed that ethane was the most consistently detected air pollutant and can be used as a tracer for natural gas operations; there are few sources of ethane other than those related to natural gas extraction. At two of the sites, elevated levels of methane levels, emissions of which were sporadic,

[504] Lara J. Cushing et al., "Up in Smoke: Characterizing the Population Exposed to Flaring from Unconventional Oil and Gas Development in the Contiguous US," *Environmental Research Letters* 16 (2021), https://doi.org/10.1088/1748-9326/abd3d4.
[505] Congmeng Lyu et al., "Evaluating Oil and Gas Contributions to Ambient Nonmethane Hydrocarbon Mixing Ratios and Ozone-Related Metrics in the Colorado Front Range," *Atmospheric Environment* 246 (2021), https://doi.org/10.1016/j.atmosenv.2020.118113.
[506] Seth N. Lyman et al., "High Ethylene and Propylene in an Area Dominated by Oil Production," *Atmosphere* 12, no. 1 (2021), https://doi.org/10.3390/atmos1201000.

corresponded to a change in isotopic signature that showed that its source was the well pad. The authors found that air pollution risk from fracking can indeed be predicted by developing a Bayesian network model.[507]

- October 20, 2020 – Between 2005 and 2017, more than 18,000 shale gas wells were permitted in the Marcellus shale region of Pennsylvania, and drilling and fracking operations moved closer to residential areas. Pennsylvania's current setback policy is that no well can be located closer than 500 feet from a home. A study investigated the sufficiency of this setback distance to protect residents from exposure to fracking-derived air pollution. Using census block data to estimate the number of people who experience levels of particulate matter that exceed air quality standards, the researchers demonstrated that these emissions could increase the number of exceedances by more than 36,000 persons in a single year, which is almost one percent of the population in Pennsylvania's Marcellus shale region. Further, most of the elevated exposures were caused by a small number of wells near populated areas. These results, according to the authors, support the idea that Pennsylvania's 500-foot setback distance is not adequate. Instead, policies should consider the number of wells per well pad and local conditions in addition to pushing wells back from residential areas.[508]

- September 9, 2020 – Ground-level ozone (smog) is created by chemical reactions between two other air pollutants: VOCs and nitrogen oxides, both of which are released from fracking operations. Using a simulation model and data from global monitoring programs, an international research team assessed the air quality impacts of increased emissions of VOCs and nitrogen oxides from U.S. oil and gas extraction operations during the 2010-2015 fracking boom. They found effects on surface ozone concentrations across a large geographical area—but especially in midwestern and central United States regions—including increased number of days during the year with elevated average ozone levels. These findings demonstrated that U.S. fracking boom significantly degraded air quality across most of the United States, can regionally negate ozone reductions from other sectors, and can impede a region's ability to meet National Ambient Air Quality Standard obligations for ozone.[509]

- June 29, 2020 – In response to public complaints about noxious odors and increased air pollution in the heavily drilled Permian Basin, the Texas Commission on Environmental Quality conducted two air monitoring surveys in December 2019 and February 2020. Results showed levels of hydrogen sulfide gas that exceeded legal limits—as high as 500 percent—in several places on multiple days. These levels are sufficient to create long-

[507] Nur H. Orak and Natalie J. Pekney, "Air Pollution Risk Associated with Unconventional Shale Gas Development," *Carbon Management* 11, no. 6 (2021): 645–51, https://doi.org/10.1080/17583004.2020.1840873.
[508] Zoya Banan and Jeremy M. Gernand, "Emissions of Particulate Matter Due to Marcellus Shale Gas Development in Pennsylvania: Mapping the Implications," *Energy Policy* 148, Part B (2021), https://doi.org/10.1016/j.enpol.2020.111979.
[509] Andrea Pozzer, Martin G. Schultz, and Detlev Helmig, "Impact of U.S. Oil and Natural Gas Emission Increases on Surface Ozone Is Most Pronounced in the Central United States," *Environmental Science & Technology* 54 (2020): 12423–33.

term health impacts. Hydrogen sulfide is poisonous to the central nervous system and can impair oxygen utilization.[510, 511, 512]

- May 8, 2020 – Along with Russia, Iran, and Iraq, the United States is one of the world's top nations for flaring. A team of atmospheric scientists measured air quality in the heavily drilled Eagle Ford Shale in southern Texas. They identified flaring as a significant source of smog-forming nitrogen oxides and carcinogenic benzene in this otherwise rural region. These results confirm those of previous studies.[513, 514]

- May 2020 – Evaporation from liquid waste pits connected to oil and gas extraction operations are a significant source of toxic air pollutants in the San Joaquin Valley air basin, according to research conducted by the California Environmental Protection Agency. These emissions include benzene, toluene, ethylbenzene, and xylene. The total emissions of this family of volatile organic compounds (total BTEX emissions) estimated in this study were then compared to the California Toxics Inventory for the San Joaquin Valley air basin, which currently does not include emissions from wastewater pits. The results showed that evaporation of toxic BTEX chemicals from the waste pits alone represented up to two percent of the air basin inventory, indicating that their inclusion in the inventory should be considered. Although these facilities are not thought to be a major source of methane emissions, the researchers note that future work could involve more regular monitoring of facilities in order to better characterize how emissions change over time.[515]

- March 12, 2020 – Fine particulate air pollution has been documented in communities near drilling and fracking operations. An interdisciplinary research team analyzed fine particulate samples collected from filters at an active well pad in Morgantown, West Virginia to determine which elements were traceable downwind and if they corresponded to measurements of particulate matter. If so, tracer elements could be used in future health studies as surrogates to estimate community exposure to air pollution from drilling

[510] Strategic Sampling Work Group, "Permian Basin Survey Region 7 Midland December 9-13, 2019" (Texas Commission on Environmental Quality Monitoring Division, April 2020), https://https://web.archive.org/web/20210528085509/https://www.tceq.texas.gov/assets/public/assistance/sblga/oil-gas/PB1912_Report.pdf.
[511] Strategic Sampling Work Group, "Permian Basin Survey Region 2 Lubbock and Region 7 Midland February 9-13, 2020" (Texas Commission on Environmental Quality Monitoring Division, June 2020), https://web.archive.org/web/20210528085519/https://www.tceq.texas.gov/assets/public/assistance/sblga/oil-gas/PB2002_Report.pdf.
[512] Dominic A. Walsh, "Some Populated Texas Areas Are at Risk of Hydrogen Sulfide Pollution According to New Report," Texas Public Radio, June 29, 2020, https://www.tpr.org/post/some-populated-texas-areas-are-risk-hydrogen-sulfide-pollution-according-new-report.
[513] Geoffrey S. Roest and Gunnar W. Schade, "Air Quality Measurements in the Western Eagle Ford Shale," *Elementa Science of the Anthropocene* 8, no. 18 (2020), https://doi.org/10.1525/elementa.414.
[514] Gunnar W. Schade, "Routine Gas Flaring Is Wasteful, Polluting and Undermeasured," *The Conversation*, July 29, 2020, https://theconversation.com/routine-gas-flaring-is-wasteful-polluting-and-undermeasured-139956?utm_source=twitter&utm_medium=bylinetwitterbutton.
[515] California Air Resources Board, "Measurement of Produced Water Air Emissions from Crude Oil and Natural Gas Operations," final, May 2020, https://ww2.arb.ca.gov/sites/default/files/2020-07/CARB%20Oil%20Wastewater%20Emissions%20Final%20Report_05.11.2020_ADA.pdf.

and fracking operations. Results suggests that magnesium might serve as a useful tracer. The team also found that well pad emissions can be measured at distances of more than four miles (7 kilometers).[516]

- January 13, 2020 – A public health team from Harvard, Columbia, and University of Colorado critiqued a study led by Judy Hess of the Shell Health Risk Science Team, and funded by Shell Oil, that had called into question epidemiological methods for ascertaining air pollution exposures and the health harms to residents living near drilling and fracking operations in the Marcellus Shale. The public health team said, "Because of the unrepresentative air monitoring locations and inappropriate statistical methods, the Hess et. al. study does not improve our understanding of the residential exposures associated with [oil and gas wells.] For these same reasons, the Hess et al. study also does not provide information useful for decisions relevant to the health of communities nearby."[517, 518] A response to this critique, also funded by Shell, argued against the validity of modeling well activity when estimating human exposures to air pollution from those wells and asserted bias in a suite of earlier studies that had identified health risks from fracking-related air pollution.[519]

- January 6, 2020 – Between 2005 and 2016, one-fifth of electric power infrastructure across the United States was redistributed as coal-fired power plants were retired and new gas-fired power plants took their place. An analysis of local air quality during this time period traced changing patterns of polluting emissions. New natural gas-fired plants created higher local pollution levels when they came on-line, but the spatial pattern and chemical composition of these pollutant were different from coal.[520]

- December 16, 2019 – An assessment of air quality changes in British Columbia from 2005 to 2018 revealed increasing nitrogen dioxide and sulfur dioxide levels in the immediate vicinity of drilling and fracking operations. Within the overall increasing trend of nitrogen dioxide levels during this time period, there was a decreasing trend between

[516] Maya Nye et al., "Use of Tracer Elements for Estimating Community Exposure to Marcellus Shale Development Operations," *International Journal of Environmental Research and Public Health* 12, no. 17 (2020): 1837, https://doi.org/10.3390/ijerph17061837.
[517] Jonathan J. Buonocore et al., "Air Monitoring Stations Far Removed from Drilling Activities Do Not Represent Residential Exposures to Marcelus Shale Air Pollutants. Response to the Paper by Hess et al. on Proximity-Based Unconventional Natural Gas Exposure Metrics," *International Journal of Environmental Research and Public Health* 17, no. 2 (2020): 504, https://doi.org/10.3390/ijerph17020504.
[518] Judy W. Hess et al., "Assessing Agreement in Exposure Classification Between Proximity-Based Metrics and Air Monitoring Data in Epidemiology Studies of Unconventional Resource Development," *International Journal of Environmental Research and Public Health* 23, no. 16 (2019): 3055, https://doi.org/10.3390/ijerph16173055.
[519] Judy W. Hess, Gerald Bachler, and Fayaz Momin, "Response to Buonocore et al. Comments on Wendt Hess et al. 'Assessing Agreement in Exposure Classification between Proximity-Based Metrics and Air Monitoring Data in Epidemiology Studies of Unconventional Resource Development,'" *International Journal of Environmental Research and Public Health* 17, no. 2 (2020): 512, https://doi.org/10.3390/ijerph17020512.
[520] Jennifer A. Burney, "The Downstream Air Pollution Impacts of the Transition From Coal to Natural Gas in the United States," *Nature Sustainability* 3 (2020): 152–60, https://doi.org/10.1038/s41893-019-0453-5.

2011-2013, a two-year period of time that corresponds to stricter compliance and enforcement of regulations for flaring.[521]

- December 6, 2019 – Although the United Kingdom and Germany have shale formations that contain methane, shale gas extraction via fracking is currently prohibited in both nations. Using modeling, a German team explored how fracking would affect ozone formation locally and, via long-distance transport, regionally. Overall, the findings demonstrate that "shale gas production in Europe can worsen ozone air quality on both the local and regional scales."[522]

- December 2, 2019 – Fracking activities are known to increase airborne nitrogen oxides, an important precursor for smog formation. Less known is how these air pollutants may be transported through atmosphere and deposited back to earth in rain and snow (wet deposition or as particles and gases (dry deposition). When nitrogen deposition exceeds a limit known as critical load, it can acidify rivers and streams and disrupt nutrient cycling in soils. A research team measured total dry deposition attributable to two fracking wells on a single well pad in the Marcellus Shale. They found that the magnitude of total nitrogen deposition per well was high enough that it would exceed critical loads in intensely fracked areas with high densities of wells.[523]

- November 12, 2019 – Wyoming is the nation's seventh largest gas-producing state with the Upper Green River Basin serving as the center of extraction. A research team studied how volatile fracking-related pollutants are transported in the air of this region. Previous estimates varied widely by methodology. Using technology that allowed for direct measurements from oil and gas facilities, the team found that 20 percent of facilities were responsible for 67 percent of the total emissions of benzene, toluene, methylbenzene, and xylenes that traveled off site. (This study was partially funded by the oil and gas industry, members of which also assisted in the collection of canister samples.)[524]

- November 11, 2019 – A long-term trend study found increases in airborne ethane, propane, butane and other organic carbon compounds in the Barnett Shale in northern Texas from 2000 to 2017. These trends mirror drilling and fracking activities in the area, specifically the changes in production volume from nearby natural gas wells and liquid condensate facilities. Benzene and xylene concentrations followed these same trends,

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[521] S. M. Nazrul Islam et al., "Impact of Natural Gas Production on Nitrogen Dioxide and Sulphur Dioxide over Northeast British Columbia, Canada," *Atmospheric Environment* 223 (2020): 117231, https://doi.org/10.1016/j.atmosenv.2019.117231.
[522] Lindsey B. Weger et al., "Modeling the Impact of a Potential Shale Gas Industry in Germany and the United Kingdom on Ozone with WRF-Chem," *Elementa Science of the Anthropocene* 7 (2019): 49, https://doi.org/10.1525/elementa.387.
[523] Justin G. Coughlin et al., "Quantifying Atmospheric Reactive Nitrogen Concentrations, Dry Deposition, and Isotope Dynamics Surrounding a Marcellus Shale Well Pad," *Atmospheric Environment* 223 (2020): 117196, https://doi.org/10.1016/j.atmosenv.2019.117196.
[524] Rachel Edie et al., "Off-Site Flux Estimates of Volatile Organic Compounds from Oil and Gas Production Facilities Using Fast-Response Instrumentation," *Environmental Science & Technology* 54, no. 3 (2020): 1385–94, https://doi.org/10.1021/acs.est.9b05621.

suggesting that fracking, rather than vehicular emissions and other urban sources, are influencing the levels of these hazardous air pollutants.[525]

- October 30, 2019 – A Colorado State University team measured emissions of volatile organic air pollutants from oil and gas wells in Colorado's Denver-Julesberg basin and Piceance basin during the periods of drilling, fracking, and flowback. Emission rates of benzene and other volatile organic compounds were highest in both basins during the flowback period—when injected fracking fluids return to the surface after a well is fracked. (This study was partially funded by the oil and gas industry.)[526]

- April 8, 2019 – Before fracking was suspended in England, a rural area near Kirby Misperton in North Yorkshire was one of the first sites in the country to seek permits for shale gas exploration and became the focus of intensive long-term environmental monitoring. As part of these efforts, air quality monitoring began in 2016, in advance of preparatory work on the site, which began in late 2017. The most significant effect noted during air monitoring was an increase in nitrogen oxide levels during the pre-operational period when equipment was brought to the site and vehicular activity increased. These effects were transitory. Hydraulic fracturing of the well did not take place, and the on-site equipment was eventually decommissioned and removed. Thereafter, air quality parameters returned to baseline.[527]

- April 1, 2019 – A University of California, Berkeley team undertook a comprehensive review of current peer-reviewed literature on hazardous air pollutants found near oil and gas extraction operations. Hazardous air pollutants are those known or suspected to cause cancer, reproductive harm, birth defects, or other serious health effects. Reviewing 37 studies, the team identified a total of 61 different hazardous air pollutants that have been detected and measured near oil and gas drilling and fracking operations. The sources of these dangerous pollutants include a wide range of equipment, activities, and facilities—from dehydrators and condensate tanks to well drilling, flowback treatment, and oil storage facilities. The team found that the production phase of oil and gas extraction has the potential to emit the highest concentrations and the most complex mixtures of hazardous air pollutants over the longest time. (During the production phase, raw oil or natural gas is flowing from the well and is processed within various ancillary equipment, all of which can emit hazardous pollutants, such as benzene.) The highest and most sustained concentrations of hazardous air pollutants were found in "regions rich in oil, wet gas, and condensate." Their results further suggest that "exposure risks can be much higher if production equipment is collocated with condensate storage and wastewater impoundments." The research team also uncovered an important disconnect between air

[525] Guo Quan Lim and Kuruvilla John, "Impact of Energy Production in the Barnett Shale Gas Region on the Measured Ambient Hydrocarbon Concentrations in Denton, Texas," *Atmospheric Pollution Research* 11, no. 2 (2020): 409–108, https://doi.org/10.1016/j.apr.2019.11.013.
[526] Arsineh Hecobian et al., "Air Toxics and Other Volatile Organic Compound Emissions from Unconventional Oil and Gas Development," *Environmental Science & Technology Letters* 6, no. 12 (2019): 720–26, https://doi.org/10.1021/acs.estlett.9b00591.
[527] Ruth M. Purvis et al., "Effects of 'Pre-Fracking' Operations on Ambient Air Quality at a Shale Gas Exploration Site in Rural North Yorkshire, England," *Science of the Total Environment* 673 (2019): 445–54, https://doi.org/10.1016/j.scitotenv.2019.04.077.

pollution monitoring studies and those reporting on health impacts. In general, the levels of air pollution detected in the monitoring studies fell short of those known to cause health impacts and yet multiple health-based studies continue to find evidence of a spatial relationship between concentrations of hazardous air pollutants and incidence of health problems among people living near oil and gas operations. These findings suggest that existing air sampling methodologies may be under-reporting emissions or that prevailing health benchmarks are inadequate to identify health problems, especially when exposures include multiple chemicals.[528]

- March 14, 2019 – Approximately 1.7 million people live within one mile of an active oil or gas well in the Los Angeles metropolitan area. A University of California pilot study investigated air pollution around active wells in this densely populated urban area and showed that, even in neighborhoods where residents are exposed to complex mixtures of air pollution from multiple sources, levels of several volatile organic pollutants are higher in communities closer to wellheads and decrease in concentration with distance away from the wellheads. These include the carcinogen benzene and n-hexane. "We were able to identify gradient behavior along the transect downwind of the target oil/natural gas facility that was likely due, in part, to emissions from the facility."[529]

- February 15, 2019 – In the first modeling study of drilling and fracking-related air pollution to include criteria air pollutants, a University of Texas, Arlington team found that concentrations of pollutants in the Barnett Shale region in north Texas were varied by terrain, with strongly sloping terrain giving the highest maximum concentrations for criteria air pollutants compared to level and moderate terrain. (Regulated by the U.S. Environmental Protection Agency [EPA] via applicable standards, the criteria air pollutants are ozone, particulate matter, lead, carbon monoxide, sulfur oxides, and nitrogen oxides.) The highest benzene and methane concentrations occurred in flat terrain and exceeded health-based standards.[530]

- January 18, 2019 – Flaring is a widely used practice for disposal of waste natural gas during oil drilling, in places that lack infrastructure for its capture and transport. Enabled by fracking, domestic oil production is at an all-time high, and this upswing has outpaced the build-out of pipelines to contain the natural gas that accompanies the oil as it flows to the surface. Using satellite technology, researchers identified 43,887 distinct oil and gas flares in the Eagle Ford Shale region of south Texas from 2012 to 2016, with a peak in activity in 2014 and an estimated 4.5 billion cubic meters of total gas volume flared over the study period. Comparing these results with well permit data showed the majority of flares (82 percent) were linked to oil wells, with more than 90 percent associated with

[528] Diane A. Garcia-Gonzales et al., "Hazardous Air Pollutants Associated with Upstream Oil and Natural Gas Development: A Critical Synthesis of Current Peer-Reviewed Literature," *Annual Review of Public Health* 40 (2019): 283–304, https://doi.org/10.1146/annurev-publhealth-040218-043715.
[529] Diane A. Garcia-Gonzales, Bhavna Shamasunder, and Michael Jerrett, "Distance Decay Gradients in Hazardous Air Pollution Concentrations Around Oil and Natural Gas Facilities in the City of Los Angeles: A Pilot Study," *Environmental Research* 173 (2019): 232–36, https://doi.org/10.1016/j.envres.2019.03.027.
[530] Farzaneh Khalaj and Melanie Sattler, "Modeling of VOCs and Criteria Pollutants from Multiple Natural Gas Well Pads in Close Proximity, for Different Terrain Conditions: A Barnett Shale Case Study," *Atmospheric Pollution Research* 10, no. 4 (2019): 1239–49, https://doi.org/10.1016/j.apr.2019.02.007.

horizontally drilled wells. These flares were not equally distributed across the region. Just five of 49 counties in the Eagle Ford Shale area accounted for 71 percent of flaring. "Our results suggest flaring may be a significant environmental exposure in parts of this region." Air pollutants from flaring operations include VOCs, polycyclic aromatic hydrocarbons, carbon monoxide, toxic heavy metals, formaldehyde, and soot.[531]

- July 27, 2018 – A report written by the United Kingdom's Air Quality Expert Group found that shale gas operations would increase air pollution (nitrogen dioxides and VOCs) both nationally and locally within the United Kingdom. However, the report languished for three years and was finally released four days after shale gas extraction was officially approved for the Lancashire region of northwest England.[532, 533]

- July 16, 2018 – A team from the Colorado Department of Public Health and Environment used existing air monitoring data sets from disparate locations to determine if air pollution levels near drilling and fracking operations are sufficient to create health problems in Colorado residents who live more than 500 feet away from a well head. Overall, they found individual VOC levels below those that are known to pose cancer and non-cancer health risks. However, the authors could not evaluate the risk of possible intermittent spikes in emissions during different phases of operation and evaluated only a subset of all VOCs emitted from drilling and fracking operations at these different phases. "Future studies are greatly needed that focus on quantifying these acute, peak exposures to people living near oil and gas operations, with particular emphasis on characterization of the volatile organic compounds identified as posing the greatest potential public health concerns, such as benzene."[534]

- July 13, 2018 – Drilling and fracking operations emit pollutants that form ozone and fine particles. Because air pollution from oil and gas operations originate from a large number of small, diffuse sources, estimating the level and location of emissions is difficult. An EPA team used a national emissions inventory for the year 2011 to characterize oil and gas emissions over space and time and to estimate the future human health burden attributable to the oil and gas sector. For the year 2025, the authors projected that oil and gas extraction activities will cause 1000 deaths across the United States from exposure to

[531] Meredith Franklin et al., "Characterizing Flaring from Unconventional Oil and Gas Operations in South Texas Using Satellite Observations," *Environmental Science & Technology* 53, no. 4 (2019): 2220–28, https://doi.org/10.1021/acs.est.8b05355.
[532] Air Quality Expert Group, "Potential Air Quality Impacts of Shale Gas Extraction in the UK" (Department for Environment, Food and Rural Affairs; Scottish Government; Welsh Government; and Department of the Environment in Northern Ireland, July 27, 2018), https://cedrec.com/cedrec_images/1807251315_AQEG_Shale_Gas_Extraction_Advice_Note_vfinal_for_publishing.pdf.
[533] Damian Carrington, "Buried UK Government Report Finds Fracking Increases Air Pollution," *The Guardian*, August 2, 2018, sec. Environment, https://www.theguardian.com/environment/2018/aug/02/buried-uk-government-report-finds-fracking-increases-air-pollution.
[534] Tami S. McMullin et al., "Exposures and Health Risks from Volatile Organic Compounds in Communities Located near Oil and Gas Exploration and Production Activities in Colorado (U.S.A.)," *International Journal of Environmental Research and Public Health* 15, no. 7 (2018): 1500, https://doi.org/10.3390/ijerph15071500.

fine particles and 970 deaths from ozone exposure, with the highest impacts in Colorado, Pennsylvania, Texas, and West Virginia.[535]

- June 13, 2018 – A British team used a new air quality forecasting model to simulate the health impacts of potential emissions from fracking operations in the United Kingdom, should large-scale fracking go forward. The results showed large projected increases in nitrogen oxides and volatile organic compounds across the U.K. airshed. These increases would contribute to approximately 110 extra premature deaths (with a range of 50-530 deaths) each year across the United Kingdom.[536]

- May 31, 2018 – Using an air pollution model that can describe the movement of pollutants in the atmosphere, a Pennsylvania study evaluated the minimum necessary distance from a fracked gas well pad to remain within air quality standards for particulate matter. The findings show that well pads that host only one active well are unlikely to expose residents living 500 feet away to unlawful levels of particulate matter. However, a typical well pad comprised of six wells with high emissions could require a minimum setback of up to 2400 feet.[537]

- May 29, 2018 – An Oregon State University team measured polycyclic aromatic hydrocarbon air pollutants near drilling and fracking operations in rural eastern Ohio. A known component of fracking-related air pollution, polycyclic aromatic hydrocarbons are linked to cancer risk, respiratory distress, and poor birth outcomes. Using both air samplers and wristbands to assess personal exposures of residents living near active or proposed well sites, the researchers found elevated air pollution levels near active well sites. Further, the wristbands from participants who lived in homes with well pads on their property registered higher levels of air pollutants than participants without wells. "These findings suggest that living or working near an active natural gas extraction well may increase personal polycyclic aromatic hydrocarbon exposure."[538]

- May 18, 2018 – A Canadian and U.S. research team monitored methane levels in urban Morgantown, West Virginia during various stages of hydraulic fracturing at a single well pad. They found that emissions at the site were greatest during the flow-back stage, a result that supports previous studies.[539]

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[535] N. Fann et al., "Assessing Human Health PM2.5 and Ozone Impacts from U.S. Oil and Natural Gas Sector Emissions in 2025," *Environmental Science & Technology* 52, no. 15 (2018): 8095–8103, https://doi.org/10.1021/acs.est.8b02050.
[536] A. T. Archibald et al., "Potential Impacts of Emissions Associated with Unconventional Hydrocarbon Extraction on UK Air Quality and Human Health," *Air Quality, Atmosphere & Health* 11 (2018): 627–37, https://doi.org/10.1007/s11869-018-0570-8.
[537] Zoya Banan and Jeremy M. Gernand, "Evaluation of Gas Well Setback Policy in the Marcellus Shale Region of Pennsylvania in Relation to Emissions of Fine Particulate Matter," *Journal of the Air & Waste Management Association* 68, no. 9 (2018): 988–1000, https://doi.org/10.1080/10962247.2018.1462866.
[538] L. Blair Paulik et al., "Environmental and Individual PAH Exposures Near Rural Natural Gas Extraction," *Environmental Pollution* 241 (2018): 397–405, https://doi.org/10.1016.j.envpol.2018.05.010.
[539] Philip J. Williams et al., "Atmospheric Impacts of a Natural Gas Development Within the Urban Context of Morgantown, West Virginia," *Science of the Total Environment* 639 (2018): 406–16, https://doi.org/10.1016/j.scitotenv.2018.04.422.

- March 27, 2018 – A team led by University of Colorado School of Public Health scientists found that air pollution levels along Colorado's heavily drilled Front Range increased with proximity to drilling and fracking operations and were sufficiently high to raise cancer risks. For people living within 500 feet of a well, lifetime cancer risks were eight times higher than the EPA's upper threshold. Elevated levels of benzene and alkanes were of particular concern. "These findings indicate that state and federal regulatory policies may not be protective of health for populations residing near oil and gas facilities."[540]

- March 21, 2018 – Evaluating 48 peer-reviewed studies that sampled air near drilling and fracking operations, researchers identified more than 200 different airborne chemicals associated with oil and gas extraction. Ethane, benzene, and n-pentane were the three most frequently detected. Twenty-six of these 200 chemicals are classified as endocrine disruptors—chemicals that can interfere with hormone systems and may affect reproduction, development, and neurological functioning.[541]

- March 18, 2018 – There are now more than 22,000 active fracking wells in the rural Eagle Ford Shale region of Texas, which has undergone a 10-fold increase in oil and gas extraction since 2010. A research team from San Francisco State University and University of Southern California used remote sensing data that incorporated infrared observations of combustion sources to estimate exposure of local residents to hazardous air pollutants from associated flaring operations. Their method confirmed extensive flaring in close proximity to homes.[542]

- February 26, 2018 – The presence of ethane and propane in the atmosphere is an indication of leaks during fossil fuel extraction and distribution, including fracking and its attendant activities, especially venting and flaring. (Fossil fuel combustion is not a source of ethane or propane.) According to a study led by a University of York team that used data collected from 20 observatories around the world, global atmospheric levels of ethane and propane have been underestimated by more than 50 percent. These results mean that hydrocarbon emissions from fossil fuel extraction activities in general—including methane—may be two to three times higher than previously presumed. Both ethane and methane are ozone precursors and contribute to the creation of smog. The authors noted that enhanced ethane and propane emission results mean higher levels of health-damaging ozone in both rural and urban areas.[543] In related press materials about this research, Ally Lewis, a co-author of the study, said, "Levels of ethane and propane

[540] Lisa M. McKenzie et al., "Ambient Nonmethane Hydrocarbon Levels Along Colorado's Northern Front Range: Acute and Chronic Health Risks," *Environmental Science & Technology* 52, no. 8 (2018): 4514–25, https://doi.org/10.1021/acs.est.7b05983.
[541] Ashley L. Bolden et al., "Exploring the Endocrine Activity of Air Pollutants Associated With Unconventional Oil and Gas Extraction," *Environmental Health* 17 (2018): 26, https://doi.org/10.1186/s12940-018-0368-z.
[542] Lara Cushing et al., "Using Satellite Observations to Estimate Exposure to Flaring: Implications for Future Studies of the Health Impacts of Unconventional Oil and Gas Operations," *Occupational & Environmental Medicine* 75, no. Suppl 1 (2018): A5–6, https://doi.org/10.1136/oemed-2018-ISEEabstracts.13.
[543] Stig G. Dalsøren et al., "Discrepancy Between Simulated and Observed Ethane and Propane Levels Explained by Underestimated Fossil Emissions," *Nature Geoscience* 11, no. 3 (2018): 178–84, https://doi.org/10.1038.s41561-018-0073-0.

declined in many places in the 1980s and 1990s, but global growth in the demand for natural gas means these trends may be reversing. The effects of higher ozone would be felt in the rural environment where it damages crops and plants, and in cities on human health." Co-author Lucy Carpenter, said, "We know that a major source of ethane and propane in the atmosphere is from 'fugitive' or unintentional escaping emissions during fossil fuel extraction and distribution. If ethane and propane are being released at greater rates than we thought, then we also need to carefully re-evaluate how much of the recent growth of methane in the atmosphere may also have come from oil and natural gas development."[544]

- February 5, 2018 – The Tropospheric Ozone Assessment Report analyzes data from all available ozone monitors around the world. Its 2018 report found that, in the United States, levels of ground-level ozone (smog) dropped steadily between 2000 and 2014 except in rural areas of the Rocky Mountain west where levels remained steady or rose. Oil and gas drilling is likely responsible. Rural areas in the western United States have fewer emission sources and yet they have been experiencing high ozone levels, especially in the winter.[545]

- November 2, 2017 – In a review paper that explores how the U.S. fracking boom has contributed to air pollution in impacted communities, Texas A&M atmospheric scientist Gunnar W. Schade identified ozone and benzene as two important chemicals of concern. Documenting trends is challenging because fracking-related air pollutants typically originate in rural places without routine air pollution monitoring. A new air monitor in the Eagle Ford Shale region allowed researchers to use fingerprinting analysis to show that 60 percent of ambient benzene in the air now comes from drilling and fracking operations, including gas flares. Before the shale boom, the majority of benzene in the region came from tailpipe emissions. "In some areas, decades-long progress on ozone air quality has stalled; in others, particularly the Uintah basin in Utah, a new ozone problem has emerged due to the fracking industry's emissions." Downwind of the Eagle Ford Shale, San Antonio's ozone levels are now trending close to 75 ppb, which exceeds the new recommended limit of 70 ppb. "The shale boom has create a new source of large-scale, diffuse hydrocarbon emissions that adversely affect air toxics levels. . . . The continued growth of the fracking industry as well as plans to remove regulations on methane emissions will not alleviate high hydrocarbon emissions and associated regional ozone problems."[546]

- April 12, 2017 – Using aircraft, a University of Michigan-led team collected plume samples from 37 flare stacks in the Bakken Shale region of North Dakota to calculate

[544] University of York, "Global Fossil Fuel Emissions of Hydrocarbons Underestimated," University of York, February 26, 2018, https://www.york.ac.uk/news-and-events/news/2018/research/global-fossil-fuel-emissions-underestimated/.
[545] Zoë L. Fleming et al., "Topospheric Ozone Assessment Report: Present-Day Ozone Distribution and Trends Relevant to Human Health," *Elementa Science of the Anthropocene* 6 (2018): 12, https://doi.org/10.1525/elementa.273.
[546] Gunnar W. Schade, "How Has the US Fracking Boom Affected Air Pollution in Shale Areas?," The Conversation, November 2, 2017, https://theconversation.com/how-has-the-us-fracking-boom-affected-air-pollution-in-shale-areas-66190.

emissions of black carbon (soot), methane, and ethane from natural gas flares. They determined that flares contribute almost 20 percent of the total emissions of methane and ethane from the Bakken region, as measured by field studies.[547]

- December 29, 2016 – Exposure to air pollutants from well pads decreases quickly with distance. However, according to recent studies, people living kilometers away from actual drilling and fracking operations also show elevated risk of disease known to be linked to air pollution. This review paper investigated the possible role that exposure to diesel exhaust from fracking-related road traffic is playing in creating public health impacts in surrounding communities. "Road traffic generated by hydraulic fracturing operations is one possible source of environmental impact whose significance has, until now, been largely neglected . . . with 4,000-6,000 vehicles visiting the well pad during the operations." As a starting point for exposure assessment, the author recommended GIS modeling studies with a focus on traffic patterns and exacerbation of pediatric asthma.[548, 549]

- October 16, 2016 – A review of recent studies documenting harm to both public health and agricultural yields from rising ozone levels identified oil and gas fields as "a major and growing source of ozone in the United States."[550]

- October 16, 2016 – In response to a lawsuit, the EPA acknowledged that its 33-year-old formula for estimating emissions from flaring operations requires revision as it may dramatically underestimate levels of health-damaging air pollutants. Emissions from flare stacks typically include carbon monoxide, nitrogen oxides, benzene, formaldehyde, and xylene, but levels of these smog-forming compounds are seldom measured directly.[551, 552]

- October 5, 2016 – A review of recent studies documented connections between oil and gas development and worsening ozone levels in western states. Drilling and fracking operations have pushed Pinedale, Wyoming out of compliance with federal ozone

[547] Alexander Gvakharia et al., "Methane, Black Carbon, and Ethane Emissions from Natural Gas Flares in the Bakken Shale, North Dakota," *Environmental Science & Technology* 51, no. 9 (2017): 5317–25, https://doi.org/10.1021/acs.est.6b05183.
[548] Michael A. McCawley, "Does Increased Traffic Flow Around Unconventional Resource Development Activities Represent the Major Respiratory Hazard to Neighboring Communities?," *Current Opinion in Pulmonary Medicine* 23, no. 2 (2017): 161–66, https://doi.org/10.1097/MCP.0000000000000361.
[549] Reid Frazier, "On Health Effects, Blame the Trucks, Not the Fracking?," The Allegheny Front, June 16, 2017, https://www.alleghenyfront.org/on-health-effects-blame-the-trucks-not-the-fracking/.
[550] Jim Robbins, "In New Ozone Alert, a Warning of Harm to Plants and People," Yale Environment 360, October 17, 2016, http://e360.yale.edu/feature/ground_level_ozone_harming_plants_humans/3044/.
[551] United States District Court for the District of Columbia, "Air Alliance Houston, et al., v. Gina McCarthy, Administrator, Environmental Protection Agency," Consent Decree, October 7, 2016, https://www.documentcloud.org/documents/3127584-Consent-Decree-on-Flares.html.
[552] David Hasemyer, "EPA Agrees Its Emissions Estimates From Flaring May Be Flawed," Inside Climate News, October 13, 2016, Agency says it will re-examine the formulas it uses, based on data provided by industry, and people near oil and gas sites hope that means cleaner air.

standards. Colorado has exceeded federal ozone limits for the past decade, a period that corresponds to a statewide boom in oil and gas drilling.[553]

- September 1, 2016 – A NASA-led research team collected whole air samples throughout the Barnett Shale basin in Texas. Chemical analysis showed that they contained benzene, hexane, and toluene at levels 2-50 times greater than the local background and similar to those seen in other intensely drilled shale basins in Colorado and Utah. There is "some evidence to suggest that public concerns for potential chronic health risks are not unwarranted."[554]

- July 23, 2016 – A study conducted at the Boulder Atmospheric Observatory examined sources of summertime ozone formation (smog) in Colorado's Front Range and found that 17 percent of locally created ozone was created by VOCs from drilling and fracking operations.[555] Colorado has exceeded the federal ozone standard for the past nine years, a period of time that corresponds to a boom in oil and gas drilling in the Wattenberg Gas Field where the number of active wells has nearly doubled.[556]

- June 13, 2016 – Between 2009 and 2014, ethane emissions in the Northern Hemisphere increased by about 400,000 tons annually, the bulk of it from North American oil and gas activity, according to research by an international team led by the University of Colorado Boulder.[557] After peaking in the 1970s, global ethane emissions began declining, primarily due to stricter air quality emission controls. In 2009, however, that downward trend reversed itself. "About 60 percent of the drop we saw in ethane levels over the past 40 years has already been made up in the past five years…. If this rate continues, we are on track to return to the maximum ethane levels we saw in the 1970s in only about three more years. We rarely see changes in atmospheric gases that quickly or dramatically," said lead researcher Detlev Helmig.[558] Samples were collected from locations around the world, but the largest increases in ethane were documented over areas of heavy oil and gas activity in the central and eastern United States. Ethane contributes to the creation of ground-level ozone pollution (smog), a known human health hazard. The authors noted that "… ozone production from these emissions has led to air quality standard exceedances in the Uintah Basin, Utah, and Upper Green River Basin, Wyoming, [oil and

[553] Anna Boiko-Weyrauch, "Ozone, Asthma And The Oil And Gas Connection," Inside Energy, October 5, 2016, http://insideenergy.org/2016/10/05/ozone-asthma-and-the-oil-and-gas-connection/.
[554] Josette E. Marrero et al., "Estimating Emissions of Toxic Hydrocarbons from Natural Gas Production Sites in the Barnett Shale Region of Northern Texas," *Environmental Science & Technology* 50, no. 19 (September 1, 2016): 10756–64, https://doi.org/10.1021/acs.est.6b02827.
[555] Erin E. McDuffie et al., "Influence of Oil and Gas Emissions on Summertime Ozone in the Coloraddo Northern Front Range," *Journal of Geophysical Research: Atmospheres* 121, no. 14 (2016): 8712–29, https://doi.org/10.1002/2016JD025265.
[556] University of Colorado at Boulder, "Accounting for Ozone: Study First to Quantify Impact of Oil and Gas Emissions on Denver's Ozone Problem," Science Daily, August 8, 2016, https://www.sciencedaily.com/releases/2016/08/160808123832.htm.
[557] Detlev Helmig et al., "Reversal of Global Atmospheric Ethane and Propane Trends Largely Due to US Oil and Natural Gas Production," *Nature Geoscience* 9 (June 13, 2016): 490–95, https://doi.org/10.1038/ngeo2721.
[558] Detlev Helmig and J. Scott, "Global Ethane Concentrations Rising Again, Says Study," News Center University of Colorado Boulder, June 13, 2016, http://www.colorado.edu/news/releases/2016/06/13/global-ethane-concentrations-rising-again-says-study.

natural gas] regions." Two scientists not involved in the study published an accompanying commentary, concluding, "There is a danger that these non-methane hydrocarbon emission changes can offset emission policies and controls aimed at reducing ozone concentrations," and "[t]hese oil and gas operations are threatening to reverse what had been an important success story: decades of declining air pollution in North America."[559] (See also the entry dated April 2, 2016 in Threats to the Climate System.)

- June 1, 2016 – Existing data on air pollutants emitted from drilling and fracking operations "support precautionary measures to protect the health of infants and children," according to a review by a team of researchers (members of which include co-authors of this Compendium). Researchers focused on exposures to ozone, particulate matter, silica dust, benzene, and formaldehyde—all of which are associated with drilling and fracking operations—noting that all are linked to adverse respiratory health effects, particularly in infants and children. Benzene, for example, emitted from gas wells, production tanks, compressors, and pipelines, is a carcinogen also linked to serious respiratory outcomes in infants and children, including pulmonary infections in newborns. As the authors emphasized, this review did not consider other air pollutants commonly associated with drilling and fracking activities, namely hydrogen sulfide, polycyclic aromatic hydrocarbons, and oxides of nitrogen. Although improved exposure assessment, air monitoring, and long-term studies are still lacking, existing evidence was sufficient for the authors to "strongly recommend precautionary measures at this time."[560]

- April 26, 2016 – About two percent of global ethane emissions originate from the Bakken shale oil and gas field, which, according to research led by University of Michigan researchers, emits 250,000 tons of ethane per year.[561] "Two percent might not sound like a lot, but the emissions we observed in this single region are 10 to 100 times larger than reported in inventories. They directly impact air quality across North America. And they're sufficient to explain much of the global shift in ethane concentrations," according to Eric Kort, first author of the study.[562] Ethane is a gas that affects climate and decreases air quality. As a greenhouse gas, ethane is the third-largest contributor to human-caused climate change. Ethane contributes to ground-based ozone pollution as it breaks down and reacts with sunlight to create smog. This surface-level ozone is linked to respiratory problems, eye irritation, and crop damage. Global ethane levels were decreasing until 2009, leading the researchers to suspect that the U.S. shale gas boom may be responsible for the global increase in levels since 2010.

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[559] Hannele Hakola and Heidi Hellén, "The Return of Ethane," *Nature Geoscience* 9 (June 13, 2016): 475–76, https://doi.org/10.1038/ngeo2736.
[560] Ellen Webb et al., "Potential Hazards of Air Pollutant Emissions From Unconventional Oil and Natural Gas Operations on the Respiratory Health of Children and Infants," *Reviews on Environmental Health* 31, no. 2 (2016): 225–43, https://doi.org/10.1515/reveh-2014-0070.
[561] E. A. Kort et al., "Fugitive Emissions From the Bakken Shale Illustrate Role of Shale Production in Global Ethane Shift," *Geophysical Research Letters* 43 (2016): 4617–23, https://doi.org/10.1002/2016GL068703.
[562] Nicole C. Moore and K. Human, "One Oil Field a Key Culprit in Global Ethane Gas Increase," Michigan News, April 26, 2016, http://ns.umich.edu/new/multimedia/videos/23735-one-oil-field-a-key-culprit-in-global-ethane-gas-increase.

- February 19, 2016 – Legally enforced minimal distances between well sites and residences are based on political compromises rather than peer-reviewed science and "may not be sufficient to reduce potential threats to human health in areas where hydraulic fracturing occurs," according to the findings of an interdisciplinary team including medical professionals and other researchers. The team incorporated geography, current regulations, historical records of blowout incidents and evacuations, thermal modeling, direct air pollution measurement, and vapor cloud modeling within the Marcellus (PA), Barnett (TX), and Niobrara (Northeastern and Northwestern Colorado and parts of Wyoming, Kansas, and Nebraska) Shale regions. The authors focused solely on well sites and excluded pipelines and compressor stations, which limited the data on explosions and evacuations and restricted air pollution results. Even so, the results showed that current natural gas well setbacks in the three areas "cannot be considered sufficient in all cases to protect public health and safety." People living within setback distances are potentially vulnerable to thermal injury during a well blowout, and they are also susceptible to exposures of benzene and hydrogen sulfide at levels above those known to cause health risks.[563]

- August 1, 2015 – "[C]linicians should be aware of the potential impact of fracking when evaluating their patients," concluded a team writing on behalf of the Occupational and Environmental Health Network of the American College of Chest Physicians. Their article stated that the over 200,000 U.S. workers employed by well-servicing companies "… are exposed to silica, diesel exhaust, and VOCs, and, at some sites, hydrogen sulfide and radon, raising concerns about occupational lung diseases, including silicosis, asthma, and lung cancer." The authors went on to say, "[i]n addition to occupational exposures, workers and nearby residents are also exposed to air pollutants emitted from various stages of fracking, including nitrogen oxides (NOx), VOCs, ozone, hazardous air pollutants, methane, and fine particulate matter." Authors pointed to several recent reversals in progress on air quality owed to fracking-related activity, including significant emissions of nitrogen oxides, a precursor of ozone, and spikes in fine particulate matter in fracking-intensive areas of Pennsylvania.[564]

- July 9, 2015 – The California Council on Science and Technology, in collaboration with the Lawrence Berkeley National Laboratory, released the second and third volumes of an extensive, peer-reviewed assessment of fracking in California. Air quality impacts are the focus of volume 2, chapter 3. The assessment found that current inventory methods underestimate methane and volatile organic chemical emissions from oil and gas operations and that fracking occurs in areas of California—most notably in the San Joaquin Valley and South Coast Air Basins—that already suffer from serious air quality problems. Further, no experimental studies of air emissions from drilling and fracking operations have ever been conducted in California. Although California has well-developed air quality inventory methods, they are "not designed to estimate well

[563] Marsha Haley et al., "Adequacy of Current State Setbacks for Directional High-Volume Hydraulic Fracturing in the Marcellus, Barnett, and Niobrara Shale Plays," *Environmental Health Perspectives* 124, no. 9 (2016): 1323–33, https://doi.org/10.1289/ehp.1510547.
[564] Richard B. Evans, David Prezant, and Yuh Chin T. Huang, "Hydraulic Fracturing (Fracking) and the Clean Air Act," *Chest* 148, no. 2 (2015): 298–300, https://doi.org/10.1378/chest.14-2582.

stimulation emissions directly, and it is not possible to determine well stimulation emissions from current inventory methods."[565]

- July 1, 2015 – In accordance with California Senate Bill No. 4, the California Division of Oil, Gas, and Geothermal Resources released a three-volume environmental impact report on oil and gas well stimulation treatments in the state (which, in California, include fracking along with acidizing and other unconventional extraction technologies that break up oil- or gas-containing rock). The Division determined that fracking and related operations can have "significant and unavoidable" impacts on air quality, including increasing ozone and other federally regulated pollutants to levels that violate air quality standards or that would make those violations worse.[566, 567]

- May 29, 2015 – Each of stage of the drilling and fracking process "… has distinct operations that occur and particular sets of air emissions that may affect the respiratory tract," wrote West Virginia University researcher Michael McCawley. Some states do have setback requirements, which "… may provide a margin of safety for fire and explosions but [do] not necessarily assure complete dilution or negligible exposure from air emissions." His paper described the specific air contaminants associated with respiratory effects for each stage of operations. For example, the actual fracking stage potentially emits diesel exhaust, VOCs, particulate matter, ozone precursors, silica, and acid mists. McCawley reviewed the health effects linked to each of the contaminant types. Though many long-term effects may not yet be apparent in shale gas regions, "[a]t a minimum, one would expect to see similar rates of respiratory disease to that found near highways with heavy traffic flow."[568]

- April 21, 2015 – In a study funded by the electric power industry, a research team found that fracking had diminished air quality in rural areas downwind of gas sites in two heavily drilled Pennsylvania counties but that concentrations of VOCs were not as high as expected based on results in other states. Methane levels were higher than previous research had found.[569] The extent to which the results can be generalized to the Marcellus basin as a whole, the authors emphasized, remains uncertain.[570]

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[565] Adam Brandt et al., "Air Quality Impacts From Well Stimulation," in *An Independent Scientific Assessment of Well Stimulation in California*, vol. II, III vols. (California Council on Science & Technology, 2015), 182–266, https://ccst.us/wp-content/uploads/160708-sb4-vol-II-3-1.pdf.

[566] California Department of Conservation, Division of Oil, Gas, and Geothermal Resources, "Analysis of Oil and Gas Well Stimulation Treatments in California, Volume II," July 1, 2015, https://web.archive.org/web/20150121160541/http://www.conservation.ca.gov/dog/SB4DEIR/Pages/SB4_DEIR_TOC.aspx.

[567] Julie Cart, "State Issues Toughest-In-the-Nation Fracking Rules," *Los Angeles Times*, July 1, 2015, http://www.latimes.com/local/lanow/la-me-ln-state-issues-fracking-rules-20150701-story.html.

[568] Michael A. McCawley, "Air Contaminants Associated With Potential Respiratory Effects From Unconventional Resource Development Activities," *Seminars in Respiratory and Critical Care Medicine* 36, no. 3 (2015): 379–87, https://doi.org/10.1055/s-0035-1549453.

[569] Susan Phillips, "Study: Lower Than Expected Air Pollutants Detected at Marcellus Drilling Sites," State Impact Pennsylvania, May 19, 2015, https://stateimpact.npr.org/pennsylvania/2015/05/19/study-lower-than-expected-air-pollutants-from-gas-drilling-sites/.

[570] J. Douglas Goetz et al., "Atmospheric Emission Characterization of Marcellus Shale Natural Gas Development Sites," *Environmental Science & Technology* 49, no. 11 (2015): 7012–20, https://doi.org/10.1021/acs.est.5b00452.

- April 15, 2015 – In a review of the literature, Colorado researchers demonstrated that four common chemical air pollutants from drilling and fracking operations—benzene, toluene, ethylbenzene, and xylene (BTEX)—are endocrine disruptors commonly found in ambient air that have the ability to interfere with human hormones at low exposure levels, including at concentrations well below EPA recommended exposure limits. Among the health conditions linked to ambient level exposures to the BTEX family of air pollutants: sperm abnormalities, reduced fetal growth, cardiovascular disease, respiratory dysfunction, and asthma.[571] "This review suggests that BTEX may…have endocrine disrupting properties at low concentrations, presenting an important line of inquiry for future research. BTEX are used globally in consumer products, and are released from motor vehicles and oil and natural gas operations that are increasingly in close proximity to homes, schools, and other places of human activity."[572]

- March 31, 2015 – University of Wyoming researchers identified a wastewater treatment and recycling facility as an important contributor to high winter ozone levels in Wyoming's Green River Basin. The facility released a signature mixture of volatile hydrocarbons, including toluene and xylene, which are ozone precursors.[573] This study documented that recycling activities can transfer volatile pollutants from water into air when fracking wastewater is cleaned up for reuse and that water treatment emissions can serve as an important point source of air pollutants.[574]

- March 26, 2015 – Fracking can pollute air hundreds of miles downwind from the well pad, according to the results of a study from University of Maryland. Researchers took hourly measurements of ethane in the air over Maryland and the greater Washington, DC area, where fracking does not occur, and compared them to ethane data from areas of West Virginia, Pennsylvania, and Ohio where it does. They found month-to-month correlations, indicating that the ethane pollution in the air over Maryland appears to be coming from drilling and fracking operations in these other states. Ethane, a minor component of natural gas, rose 30 percent in the air over the Baltimore and Washington DC area since 2010, even as other air pollutants declined in concentration. By contrast, no increase in ethane levels were found in Atlanta, Georgia, which is not downwind of

[571] Brian Bienkowski, "Scientists Warn of Hormone Impacts From Benzene, Xylene, Other Common Solvents," Environmental Health News, April 15, 2015, http://www.environmentalhealthnews.org/ehs/news/2015/apr/endocrine-disruption-hormones-benzene-solvents.
[572] Ashley L. Bolden, Carol F. Kwiatkowski, and Theo Colborn, "New Look at BTEX: Are Ambient Levels a Problem?," *Environmental Science & Technology* 49, no. 9 (2015): 5261–76, https://doi.org/10.1021/es505316f.
[573] R. A. Field et al., "Influence of Oil and Gas Field Operations on Spatial and Temporal Distributions of Atmospheric Non-Methane Hydrocarbons and Their Effect on Ozone Formation in Winter," *Atmospheric Chemistry and Physics* 15 (2015): 3527–42, https://doi.org/10.5194/acp-15-3527-2015.
[574] Amanda Peterka, "Study Links Wyoming Winter Ozone to Drillers' Wastewater Plant," *WyoFile*, April 2, 2015, https://web.archive.org/web/20150403112532/https://www.wyofile.com/study-links-wyoming-winter-ozone-drillers-wastewater-plant/.

fracking operations.[575, 576] Given this evidence for widespread ethane leakage, the paper's lead author asked how much methane and other, more reactive emissions might be escaping from wells, noting that "a substantial amount of hydrocarbons" are emitted as a result of flowback procedures following the fracturing process.[577]

- February 27, 2015 – A team of researchers from University of Texas, funded in part by the gas industry, examined ozone (smog) production resulting from natural gas extraction and use in Texas. Previous research by this team had found that the increased use of natural gas for generating electricity, as a replacement for coal, contributed to overall reductions in daily maximum ozone concentrations in northeastern Texas. By contrast, the results of this study found an increase in ozone in the Eagle Ford Shale area of south Texas. The Eagle Ford Shale is upwind from both Austin and San Antonio.[578] A potent greenhouse gas, methane is also a precursor for ground-level ozone and hence a contributor to smog formation.

- January 16, 2015 – Researchers from a number of universities, including the University of New Hampshire and Appalachian State University, used a source apportionment model to estimate the contribution of natural gas extraction activities to overall air pollution, including ozone, in heavily drilled southwest Pennsylvania. This regional air sampling effort demonstrated significant changes in atmospheric chemistry from drilling and fracking operations there. The researchers found that drilling and fracking operations may affect compliance with ozone standards.[579]

- November 20, 2014 – The Texas Commission on Environmental Quality confirmed high levels of benzene emissions and other VOCs around an oil and gas facility in the Eagle Ford Shale. Symptoms reported by local residents were consistent with those known to be associated with exposure to such chemicals.[580]

- November 14, 2014 – A University of Colorado at Boulder research team found that residential areas in intensely drilled northeastern Colorado have high levels of fracking-related air pollutants, including benzene. In some cases, concentrations exceed those

[575] Timothy Vinciguerra et al., "Regional Air Quality Impacts of Hydraulic Fracturing and Shale Natural Gas Activity: Evidence From Ambient VOC Observations," *Atmospheric Environment* 110 (2015): 144–50, https://doi.org/10.1016/j.atmosenv.2015.03.056.
[576] Katie Valentine, "Fracking Wells Could Pollute The Air Hundreds Of Miles Away," *Climate Progress*, April 30, 2015, https://archive.thinkprogress.org/fracking-wells-could-pollute-the-air-hundreds-of-miles-away-e65ff4f3b24c/.
[577] F. Levine and L. Tune, "Emissions from Natural Gas Wells May Travel Far Downwind," Department of Chemical & Biomolecular Engineering, University of Maryland, April 30, 2015, https://chbe.umd.edu/news/story/emissions-from-natural-gas-wells-may-travel-far-downwind.
[578] Adam P. Pacsi et al., "Regional Ozone Impacts of Increased Natural Gas Use in the Texas Power Sector and Development in the Eagle Ford Shale," *Environmental Science & Technology* 49, no. 6 (2015): 3966–73, https://doi.org/10.1021/es5055012.
[579] Robert F. Swarthout et al., "Impact of Marcellus Shale Natural Gas Development in Southwest Pennsylvania on Volatile Organic Compound Emissions and Regional Air Quality," *Environmental Science & Technology* 49, no. 5 (2015): 3175–84, https://doi.org/10.1021/es504315f.
[580] Barry Davis, "TCEQ Memo Proves Toxic Chemicals Are Being Released in the Eagle Ford Shale," *USA Today*, November 20, 2014, https://www.usatoday.com/story/news/investigations/i-team/2014/11/20/benzene-oil-toxic-fumes/70020596/.

found in large urban centers and are within the range of exposures known to be linked to chronic health effects. According to the study, "High ozone levels are a significant health concern, as are potential health impacts from chronic exposure to primary emissions of non-methane hydrocarbons (NMHC) for residents living near wells." The study also noted that tighter regulations have not resulted in lower air pollution levels, "Even though the volume of emissions per well may be decreasing, the rapid and continuing increase in the number of wells may potentially negate any real improvements to the air quality situation."[581]

- October 30, 2014 – A research team assembled by University at Albany Institute for Health and the Environment identified eight highly toxic chemicals in air samples collected near fracking and associated infrastructure sites across five states: Arkansas, Colorado, Pennsylvania, Ohio, and Wyoming. The most common airborne chemicals detected included two proven human carcinogens (benzene and formaldehyde) and two potent neurotoxicants (hexane and hydrogen sulfide). In 29 out of 76 samples, concentrations far exceeded federal health and safety standards, sometimes by several orders of magnitude. Further, high levels of pollutants were detected at distances exceeding legal setback distances from wellheads to homes. Highly elevated levels of formaldehyde, for example, were found up to a half-mile from a wellhead. In Arkansas, seven air samples contained formaldehyde at levels up to 60 times the level known to raise the risk for cancer.[582] "This is a significant public health risk," said lead author David O. Carpenter, MD, in an accompanying interview: "Cancer has a long latency, so you're not seeing an elevation in cancer in these communities. But five, 10, 15 years from now, elevation in cancer is almost certain to happen."[583]

- October 21, 2014 – Responding to health concerns by local residents, a research team from University of Cincinnati and Oregon State University found high levels of air pollution in heavily drilled areas of rural Carroll County, Ohio. Air monitors showed 32 different hydrocarbon-based air pollutants, including the carcinogens naphthalene and benzo[a]pyrene.[584] The researchers plan additional monitoring and analysis.

- October 21, 2014 – Using a mobile laboratory designed by NOAA, a research team from the University of Colorado at Boulder, the NOAA Earth System Research Laboratory, and the Karlsruhe Institute of Technology looked at air pollution from drilling and fracking operations in Utah's Uintah Basin. The researchers found that drilling and fracking emit prodigious amounts of volatile organic air pollutants, including benzene, toluene, and methane, all of which are precursors for ground-level ozone (smog).

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[581] Chelsea R. Thompson, Jacques Hueber, and Detlev Helmig, "Influence of Oil and Gas Emissions on Ambient Atmospheric Non-Methane Hydrocarbons in Residential Areas of Northeastern Colorado," *Elementa: Science of the Anthropocene* 3 (2014), https://doi.org/10.12952/journal.elementa.000035.
[582] Gregg P. Macey et al., "Air Concentrations of Volatile Compounds Near Oil and Gas Production: A Community-Based Exploratory Study," *Environmental Health* 13, no. 82 (2014), https://doi.org/10.1186/1476-069X-13-82.
[583] Alan Neuhauser, "Toxic Chemicals, Carcinogens Skyrocket Near Fracking Sites," *U.S. News*, October 30, 2014, http://www.usnews.com/news/articles/2014/10/30/toxic-chemicals-and-carcinogens-skyrocket-near-fracking-sites-study-says.
[584] Environmental Health Sciences Center, "List of 62 PAH Analyzed in Carroll County, OH," Oregon State University, 2014, http://ehsc.oregonstate.edu/air/62PAHList of 62 PAH Analyzed in Carroll County, OH.

Multiple pieces of equipment on and off the well pad, including condensate tanks, compressors, dehydrators, and pumps, served as the sources of these emissions. This research shows that drilling and fracking activities are the cause of the extraordinarily high levels of winter smog in the remote Uintah basin—which regularly exceed air quality standards and rival that of downtown Los Angeles.[585]

- October 2, 2014 – A joint investigation by *Inside Climate News* and the Center for Public Integrity found that toxic air emissions wafting from fracking waste pits in Texas are unmonitored and unregulated due to federal exemptions that classify oil and gas field waste as non-hazardous.[586]

- October 1, 2014 – In a major paper published in *Nature*, an international team led by the National Oceanic and Atmospheric Administration demonstrated that exceptionally high emissions of VOCs explain how drilling and fracking operations in Utah's Uintah Basin create extreme wintertime ozone events even in the absence of abundant ultraviolet light and water vapor, which are typically required to produce ground-level ozone (smog). Current air pollution trends in the United States are toward lower nitrogen oxides from urban sources and power generation, but increasing methane and VOCs from oil and gas extraction activities threaten to reverse decades of progress in attaining cleaner air. According to the study, the consequences for public health are "as yet unrecognized."[587]

- September 6, 2014 – As part of a comparative lifecycle analysis, a British team from the University of Manchester found that shale gas extracted via fracking in the United Kingdom would generate more smog than any other energy source evaluated (coal, conventional and liquefied gas, nuclear, wind, and solar). Leakage of vaporous organic compounds during the necessary removal of hydrogen sulfide gas, along with the venting of gas both during drilling and during the process of making the well ready for production, were major contributors. "In comparison to other technologies, shale gas has high [photochemical smog]. In the central case, it is worse than solar PV, offshore wind and nuclear power by factors of 3, 26 and 45, respectively. Even in the best case, wind and nuclear power are still preferable (by factors of 3.3 and 5.6 respectively)."[588]

- September 2014 – ShaleTest Environmental Testing conducted ambient air quality tests and gas-finder infrared video for several children's play areas in North Texas that are located in close proximity to shale gas development. The results showed a large number of compounds detected above the Method Reporting Limit (the minimum quantity of the compound that can be confidently determined by the laboratory). Air sampling found

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[585] C. Warneke et al., "Volatile Organic Compound Emissions From the Oil and Natural Gas Industry in the Uintah Basin, Utah: Oil and Gas Well Pad Emissions Compared to Ambient Air Composition," *Atmospheric Chemistry and Physics* 14 (2014): 10977–88, https://doi.org/10.5194/acp-14-10977-2014.
[586] David Hasemyer, "Open Pits Offer Cheap Disposal for Fracking Sludge, But Health Worries Mount," *Inside Climate News*, October 2, 2014, http://www.publicintegrity.org/2014/10/02/15826/open-pits-offer-cheap-disposal-fracking-sludge-health-worries-mount.
[587] Peter M. Edwards et al., "High Winter Ozone Pollution from Carbonyl Photolysis in an Oil and Gas Basin," *Nature* 514 (2014): 351–54, https://doi.org/10.1038/nature13767.
[588] Laurence Stamford and Adisa Azapagic, "Life Cycle Environmental Impacts of UK Shale Gas," *Applied Energy* 134 (2014): 506–18, https://doi.org/10.1016/j.apenergy.2014.08.063.

three known/suspected carcinogens, and a number of other compounds associated with significant health effects. Benzene results from Denton, Dish, and Fort Worth are particularly alarming since they exceeded the long-term ambient air limits set by the Texas Commission on Environmental Quality, and benzene is a known carcinogen. "Benzene was found at all but one sampling location …. This is particularly noteworthy as benzene is a known carcinogen (based on evidence from studies in both people and lab animals), AND because it exceeds [levels above which effects have the potential to occur.]"[589]

- August 24, 2014 – A *Salt Lake City Tribune* investigation found that evaporation from 14 fracking waste pits in western Colorado has added tons of toxic chemicals to Utah's air in the last six years. Further, the company responsible operated with no permit, underreported its emissions and provided faulty data to regulators.[590]

- August 2014 – A four-part investigation by the *San Antonio Express-News* found that natural gas flaring in the Eagle Ford Shale in 2012 contributed more than 15,000 tons of VOCs and other contaminants to the air of southern Texas—which is roughly equivalent to the pollution that would be released annually by six oil refineries. No state or federal agency is tracking the emissions from individual flares.[591]

- June 26, 2014 – Public health professionals at the Southwest Pennsylvania Environmental Health Project reported significant recurrent spikes in the amount of particulate matter in the air inside of residential homes located near drilling and fracking operations. Captured by indoor air monitors, the spikes tend to occur at night when stable atmospheric conditions hold particulate matter low to the ground. Director Raina Ripple emphasized that spikes in airborne particulate matter are likely to cause acute health impacts in community members. She added, "What the long-term effects are going to be, we're not certain."[592]

- May 8, 2014 – Researchers at NOAA found high levels of methane leaks as well as benzene and smog-forming VOCs in the air over oil and gas drilling areas in Colorado. Researchers found methane emissions three times higher than previously estimated and benzene and VOC levels seven times higher than estimated by government agencies. The

[589] ShaleTest Environmental Testing, "Project Playground: Cleaner Air for Active Kids," September 2014, https://web.archive.org/web/20150913195017/http://www.shaletest.org/wp-content/uploads/2014/09/ProjectPlaygoundPatagoniaReport-5-1.pdf.
[590] Brian Maffly, "Utah Grapples With Toxic Water From Oil and Gas Industry," *The Salt Lake Tribune*, August 28, 2014, http://www.sltrib.com/sltrib/news/58298470-78/danish-flats-ponds-company.html.
[591] John Tedesco and Jennifer Hiller, "Up in Flames: Flare in Eagle Ford Shale Wasting Natural Gas," *San Antonio Express-News*, August 2014, http://www.expressnews.com/business/eagleford/item/Up-in-Flames-Day-1-Flares-in-Eagle-Ford-Shale-32626.php.
[592] Jeff McMahon, "Air Pollution Spikes In Homes Near Fracking Wells," *Forbes*, June 26, 2014, Air Pollution Spikes In Homes Near Fracking Wells.

Denver Post noted that Colorado's Front Range has failed to meet federal ozone air quality standards for years.[593]

- April 26, 2014 – A Texas jury awarded a family $2.8 million because, according to the lawsuit, a fracking company operating on property nearby had "created a 'private nuisance' by producing harmful air pollution and exposing [members of the affected family] to harmful emissions of volatile organic compounds, toxic air pollutants and diesel exhaust." The family's 11-year-old daughter became ill, and family members suffered a range of symptoms, including "nosebleeds, vision problems, nausea, rashes, blood pressure issues."[594] Because drilling did not occur on their property, the family had initially been unaware that their symptoms were caused by activities around them.

- April 16, 2014 – Reviewing the peer-review literature to date of "direct pertinence to the environmental public health and environmental exposure pathways," a U.S. team of researchers concluded: "[a] number of studies suggest that shale gas development contributes to levels of ambient air concentrations known to be associated with increased risk of morbidity and mortality."[595]

- April 11, 2014 – A modeling study commissioned by the state of Texas made striking projections about worsening air quality in the Eagle Ford Shale. Findings included the possibility of a 281 percent increase in emissions of VOCs. Some VOCs cause respiratory and neurological problems; others, like benzene, are also carcinogens. Another finding was that nitrogen oxides—which react with VOCs in sunlight to create ground-level ozone, the main component of smog—increased 69 percent during the peak ozone season.[596]

- March 29, 2014 – Scientists warn that current methods of collecting and analyzing emissions data do not accurately assess health risks. Researchers with the Southwest Pennsylvania Environmental Health Project showed that methods do not adequately measure the intensity, frequency, or durations of community exposure to the toxic chemicals routinely released from drilling and fracking activities. They found that exposures may be underestimated by an order of magnitude, mixtures of chemicals are not taken into account, and local weather conditions and vulnerable populations are ignored.[597]

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[593] Bruce Finley, "Scientists Flying Over Colorado Oil Boom Find Worse Air Pollution," *The Denver Post*, May 7, 2014, sec. Environment, http://www.denverpost.com/environment/ci_25719742/scientists-flying-over-colorado-oil-boom-find-worse.
[594] Jason Morris, "Texas Family Plagued With Ailments Gets $3M in 1st-of-Its-Kind Fracking Judgment," *CNN*, April 26, 2014, http://www.cnn.com/2014/04/25/justice/texas-family-wins-fracking-lawsuit/.
[595] Seth B. C. Shonkoff, Jake Hays, and Madelon Finkel, "Environmental Public Health Dimensions of Shale and Tight Gas Development," *Environmental Health Perspectives* 122, no. 8 (2014), https://doi.org/10.1289/ehp.1307866.
[596] Jim Morris, Lisa Song, and David Hasemayer, "Report: Air Quality to Worsen in Eagle Ford Shale," *The Texas Tribune*, April 11, 2014, http://www.texastribune.org/2014/04/11/report-air-quality-worsen-eagle-ford-shale/.
[597] David Brown et al., "Understanding Exposure From Natural Gas Drilling Puts Current Air Standards to the Test," *Reviews on Environmental Health* 29, no. 4 (n.d.): 277–92, https://doi.org/10.1515/reveh-2014-0002.

- March 27, 2014 – University of Texas research pointed to "potentially false assurances" in response to community health concerns in shale gas development areas. Dramatic shortcomings in air pollution monitoring to date include no accounting for cumulative toxic emissions or children's exposures during critical developmental stages, and the potential interactive effects of mixtures of chemicals. Chemical mixtures of concern include benzene, toluene, ethylbenzene, and xylenes.[598, 599]

- March 13, 2014 – VOCs emitted in Utah's heavily drilled Uintah Basin led to 39 winter days exceeding the EPA's eight-hour National Ambient Air Quality Standards level for ozone pollutants the previous winter. "Levels above this threshold are considered to be harmful to human health, and high levels of ozone are known to cause respiratory distress and be responsible for an estimated 5,000 premature deaths in the U.S. per year," according to researchers at the University of Colorado. Their observations "reveal a strong causal link between oil and gas emissions, accumulation of air toxics, and significant production of ozone in the atmospheric surface layer."[600] Researchers estimated that total annual VOC emissions at the fracking sites are equivalent to those of about 100 million cars.[601]

- March 3, 2014 – In a report summarizing "the current understanding of local and regional air quality impacts of natural gas extraction, production, and use," a group of researchers from NOAA, Stanford, Duke, and other institutions described what is known and unknown with regard to air emissions including greenhouse gases, ozone precursors (VOCs and nitrogen oxides), air toxics, and particulates. Crystalline silica was also discussed, including as a concern for people living near well pads and production staging areas.[602]

- February 18, 2014 – An eight-month investigation by the *Weather Channel*, the *Center for Public Integrity,* and *Inside Climate News* into fracking in the Eagle Ford Shale in Texas revealed that fracking is "releasing a toxic soup of chemicals into the air." They noted very poor monitoring by the state of Texas and reported on hundreds of air complaints filed relating to air pollution associated with fracking.[603]

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[598] Rachael Rawlins, "Planning for Fracking on the Barnett Shale: Urban Air Pollution, Improving Health Based Regulation, and the Role of Local Governments," *Virginia Environmental Law Journal* 31, no. 2 (2013): 223–306.
[599] University of Texas at Austin, "Air Pollution and Hydraulic Fracturing: Better Monitoring, Planning and Tracking of Health Effects Needed in Texas," *UT News*, March 27, 2014, https://news.utexas.edu/2014/03/27/air-pollution-and-hydraulic-fracturing-better-monitoring-planning-and-tracking-of-health-effects-needed-in-texas/.
[600] D. Helmig et al., "Highly Elevated Atmospheric Levels of Volatile Organic Compounds in the Uintah Basin, Utah," *Environmental Science & Technology* 48, no. 9 (2014): 4707–15, https://doi.org/10.1021/es405046r.
[601] Deirdre Lockwood, "Harmful Air Pollutants Build Up Near Oil And Gas Fields," *Chemical & Engineering News*, March 25, 2014, http://cen.acs.org/articles/92/web/2014/03/Harmful-Air-Pollutants-Build-Near.html.
[602] Christopher W. Moore et al., "Air Impacts of Increased Natural Gas Acquisition, Processing, and Use: A Critical Review," *Environmental Science & Technology* 48, no. 15 (2014): 8349–5359, https://doi.org/10.1021/es4053472.
[603] *Fracking the Eagle Ford Shale: Big Oil and Bad Air on the Texas Prairie* (The Weather Channel, 2014), https://insideclimatenews.org/project/fracking-the-eagle-ford-shale/#:~:text=Fracking%20the%20Eagle%20Ford%20Shale%20Big%20Oil%20%26,overtook%20the%20oil%20and%20gas%20fields%20of%20Texas.

- December 18, 2013 – An interdisciplinary group of researchers in Texas collected air samples in residential areas near shale gas extraction and production, going beyond previous Barnett Shale studies by including emissions from the whole range of production equipment. They found that most areas had "atmospheric methane concentrations considerably higher than reported urban background concentrations," and many toxic chemicals were "strongly associated" with compressor stations.[604]

- December 10, 2013 – Health department testing at fracking sites in West Virginia revealed dangerous levels of benzene in the air. Wheeling-Ohio County Health Department Administrator Howard Gamble stated, "The levels of benzene really pop out. The amounts they were seeing were at levels of concern. The concerns of the public are validated."[605]

- October 11, 2013 – Air sampling before, during, and after drilling and fracking of a new natural gas well pad in rural western Colorado documented the presence of the toxic solvent methylene chloride, along with several polycyclic aromatic hydrocarbons at "concentrations greater than those at which prenatally exposed children in urban studies had lower developmental and IQ scores." The study linked this single well pad to more than 50 airborne chemicals, 44 of which have known health effects. [606]

- September 19, 2013 – In Texas, air monitoring data in the Eagle Ford Shale area revealed potentially dangerous exposures of nearby residents to hazardous air pollutants, including cancer-causing benzene and the neurological toxicant, hydrogen sulfide.[607]

- September 13, 2013 – A study by researchers at the University of California at Irvine found dangerous levels of VOCs in Canada's "Industrial Heartland" where there are more than 40 oil, gas, and chemical facilities. The researchers noted high levels of hematopoietic cancers (leukemia and non-Hodgkin's lymphoma) in men who live closer to the facilities.[608]

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[604] Alisa Rich, James P. Gover, and Melanie L. Sattler, "An Exploratory Study of Air Emissions Associated With Shale Gas Development and Production in the Barnett Shale," *Journal of the Air & Waste Management Association* 64, no. 1 (2014): 61–72, https://doi.org/10.1080/10962247.2013.832713.

[605] C. Junkins, "Health Dept. Concerned About Benzene Emissions Near Local Gas Drilling Sites," *The Intelligencer, Wheeling News-Register*, December 10, 2013, sec. Community, https://www.theintelligencer.net/news/community/2013/12/health-dept-concerned-about-benzene-emissions-near-local-gas-drilling-sites/.

[606] Theo Colborn et al., "An Exploratory Study of Air Quality Near Natural Gas Operations," *Human and Ecological Risk Assessment: An International Journal* 20, no. 1 (2014): 86–105, https://doi.org/10.1080/10807039.2012.749447.

[607] Sharon Wilson, Lisa Sumi, and Wilma Subra, "Reckless Endangerment While Fracking the Eagle Ford Shale" (Earthworks, September 19, 2013), http://www.earthworksaction.org/library/detail/reckless_endangerment_in_the_eagle_ford_shale#.UkGi-4Y3uSo.

[608] Isobel J. Simpson et al., "Air Quality in the Industrial Heartland of Alberta, Canada and Potential Impacts on Human Health," *Atmospheric Environment* 81 (2013): 702–9, https://doi.org/10.1016/j.atmosenv.2013.09.017.

- April 29, 2013 – Using American Lung Association data, researchers with the Environmental Defense Fund determined that air quality in rural areas with fracking was worse than air quality in urban areas.[609]

- March 2013 – A review of regional air quality damages in parts of Pennsylvania in 2012 from Marcellus Shale development found that air pollution was a significant concern, with regional damages ranging from $7.2-$32 million in 2011.[610]

- February 27, 2013 – In a letter from Concerned Health Professionals of New York to Governor Andrew Cuomo, a coalition of hundreds of health organizations, scientists, medical experts, elected officials, and environmental organizations noted serious health concerns about the prospects of fracking in New York State, making specific note of air pollution.[611] Signatory organizations included the American Academy of Pediatrics of New York, the American Lung Association of New York, and Physicians for Social Responsibility. The New York State Medical Society, representing 30,000 medical professionals, has issued similar statements.[612]

- January 2, 2013 – A NOAA study identified emissions from oil and gas fields in Utah as a significant source of pollutants that contribute to ozone problems.[613] Exposure to elevated levels of ground-level ozone is known to worsen asthma and has been linked to respiratory illnesses and increased risk of stroke and heart attack.[614]

- July 18, 2012 – A study by the Houston Advanced Research Center modeled ozone formation from a natural gas processing facility using accepted emissions estimates and showed that regular operations could significantly raise levels of ground-level ozone (smog) in the Barnett Shale in Texas and that gas flaring further contributed to ozone levels.[615]

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[609] Dan Grossman, "Clean Air Report Card: CO, WY Counties Get F's Due To Oil And Gas Pollution," *Environmental Defense Fund* (blog), April 29, 2013, http://blogs.edf.org/energyexchange/2013/04/29/clean-air-report-card-co-wy-counties-get-fs-due-to-oil-and-gas-pollution/#sthash.FXRV6Nxi.dpuf.
[610] Aviva Litovitz et al., "Estimation of Regional Air-Quality Damages From Marcellus Shale Natural Gas Extraction in Pennsylvania," *Environmental Research Letters* 8, no. 1 (2013), https://doi.org/10.1088/1748-9326/8/1/014017.
[611] Concerned Health Professionals of NY, "Letter to Governor Cuomo," February 27, 2013, http://concernedhealthny.org/letters-to-governor-cuomo/.
[612] J. Campbell, "Fracking Roundup: Gas Prices Up; Medical Society Wants Moratorium," *Politics on the Hudson* (blog), April 17, 2013, http://polhudson.lohudblogs.com/2013/04/17/fracking-roundup-gas-prices-up-medical-society-wants-moratorium/.
[613] Jeff Tollefson, "Methane Leaks Erode Green Credentials of Natural Gas," *Nature* 493 (2013): 12, https://doi.org/10.1038/493012a.pdf.
[614] American Lung Association, "State of the Air 2013: American Lung Association Report Reveals America's Most Polluted Cities," April 24, 2013.
[615] Eduardo P. Olaguer, "The Potential Near-Source Ozone Impacts of Upstream Oil and Gas Industry Emissions," *Journal of the Air & Waste Management Association* 62, no. 8 (2012): 966–77, https://doi.org/10.1080/10962247.2012.688923.

- March 19, 2012 – A Colorado School of Public Health study found air pollutants near fracking sites linked to neurological and respiratory problems and cancer.[616, 617] The study, based on three years of monitoring at Colorado sites, found a number of "potentially toxic petroleum hydrocarbons in the air near gas wells including benzene, ethylbenzene, toluene, and xylene." Lisa McKenzie, PhD, MPH, lead author of the study and research associate at the Colorado School of Public Health, said, "Our data show that it is important to include air pollution in the national dialogue on natural gas development that has focused largely on water exposures to hydraulic fracturing."[618]

- December 12, 2011 – Cancer specialists, cancer advocacy organizations, and health organizations summarized the cancer risks posed by all stages of the shale gas extraction process in a letter to New York Governor Andrew Cuomo.[619]

- October 5, 2011 – More than 250 medical experts and health organizations reviewed the multiple health risks from fracking in a letter sent to New York Governor Andrew Cuomo.[620]

- April 21, 2011 – *Environment & Energy (E&E)* reported that ozone levels exceeding federal health standards in Utah's Uintah Basin, as well as wintertime ozone problems in other parts of the Intermountain West, stem from oil and gas extraction. Levels reached nearly twice the federal standard, potentially dangerous even for healthy adults to breathe. Keith Guille, spokesman for the Wyoming Department of Environmental Quality, said, "We recognize that definitely the main contributor to the emissions that are out there is the oil and gas industry…."[621]

- March 8, 2011 – The Associated Press reported that gas drilling in some remote areas of Wyoming caused a decline of air quality from pristine mountain air to levels of smog and pollution worse than Los Angeles on its worst days, resulting in residents complaining of watery eyes, shortness of breath, and bloody noses.[622]

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[616] David Kelly, "Study Shows Air Emissions Near Fracking Sites May Have Serious Health Impacts," *University of Colorado Denver*, March 19, 2012, https://news.cuanschutz.edu/news-stories/health-impacts-of-fracking-emissions.
[617] Lisa M. McKenzie et al., "Human Health Risk Assessment Of Air Emissions From Development Of Unconventional Natural Gas Resources," *Science of the Total Environment* 424 (2012): 79–87, https://doi.org/10.1016/j.scitotenv.2012.02.018.
[618] Neela Banerjee, "Study: 'Fracking' May Increase Air Pollution Health Risks," *Los Angeles Times*, March 20, 2012, https://www.latimes.com/science/la-xpm-2012-mar-20-la-me-gs-fracking-increases-air-pollution-health-risks-to-residents-20120320-story.html.
[619] Physicians, Scientists & Engineers for Health Energy, "Appeal to Gov. Cuomo to Consider Cancer Risks Re: High Volume Hydraulic Fracturing for Natural Gas," Letter to A. Cuomo, December 12, 2011, http://steingraber.com/wp-content/uploads/CancerFrackingDec12.pdf.
[620] Concerned Health Professionals of NY, "Letter to Governor Cuomo," October 5, 2011, https://concernedhealthny.org/letters-to-governor-cuomo/.
[621] Scott Streater, "Air Pollution: Winter Ozone Problem Continues to Mystify Regulators, Industry.," *E&E News*, April 21, 2011, https://web.archive.org/web/20131024193123/http://www.eenews.net/stories/1059948108.
[622] Mead Gruver, "Wyoming Is Beset by a Big-City Problem: Smog," *USA Today*, March 8, 2011, http://usatoday30.usatoday.com/money/industries/energy/2011-03-08-natural-gas-ozone-wyoming_N.htm.

- November 18, 2010 – A study of air quality in the Haynesville Shale region of east Texas, northern Louisiana, and southwestern Arkansas found that shale oil and gas extraction activities contributed significantly to ground-level ozone (smog) via high emissions of ozone precursors, including VOCs and nitrogen oxides.[623] Ozone is a key risk factor for asthma and other respiratory and cardiovascular illnesses.[624, 625, 626, 627]

- September 2010 – A health assessment by the Colorado School of Public Health for gas development in Garfield County, Colorado determined that air pollution will likely "be high enough to cause short-term and long-term disease, especially for residents living near gas wells. Health effects may include respiratory disease, neurological problems, birth defects and cancer."[628, 629]

- January 27, 2010 – Of 94 drilling sites tested for benzene in air over the Barnett Shale, the Texas Commission on Environmental Quality discovered two well sites emitting what they determined to be "extremely high levels" and another 19 emitting elevated levels.[630]

[623] Susan Kemball-Cook et al., "Ozone Impacts of Natural Gas Development in the Haynesville Shale," *Environmental Science & Technology* 15, no. 44 (2010): 9357-9363, https://doi.org/10.1021/es1021137.
[624] United States Environmental Protection Agency, "Integrated Science Assessment (ISA) for Ozone and Related Photochemical Oxidants," EPA, 2013, https://www.epa.gov/isa/integrated-science-assessment-isa-ozone-and-related-photochemical-oxidants.
[625] Anoop S. B. Shah et al., "Short Term Exposure to Air Pollution and Stroke: Systematic Review and Meta-Analysis," *British Medical Journal* 350, no. h1295 (2015), https://doi.org/10.1136/bmj.h1295.
[626] Anoop S. B. Shah et al., "Global Association of Air Pollution and Heart Failure: A Systematic Review and Meta-Analysis," *Lancet* 382, no. 9897 (2013): 1039–48, https://doi.org/10.1016/S0140-6736(13)60898-3.
[627] Orrin Myers et al., "The Association Between Ambient Air Quality Ozone Levels and Medical Visits for Asthma in San Juan County" (New Mexico Department of Health, Environmental Health Epidemiology Bureau Epidemiology and Response Division, August 2007), https://fossil.energy.gov/ng_regulation/sites/default/files/programs/gasregulation/authorizations/2012/applications/sierra_exhibits_12_100_LNG/Ex._51_-_Myers_Association_Btwn_Ambient.pdf.
[628] R. Witter et al., "Health Impact Assessment for Battlement Mesa, Garfield County Colorado" (Garfield County, Colorado, 2010), https://www.garfield-county.com/environmental-health/battlement-mesa-health-impact-assessment-draft1/.
[629] "Battlement Mesa HIA/EHMS" (Garfield County, Colorado, November 30, 2013), https://www.garfield-county.com/environmental-health/battlement-mesa-health-impact-assessment-ehms/.
[630] John McFarland, "Agency Finds High Benzene Levels on Barnett Shale," *Boston Globe*, January 27, 2010, http://archive.boston.com/business/articles/2010/01/27/agency_finds_high_benzene_levels_on_barnett_shale/.

Water contamination

Drilling and fracking activities, and associated wastewater disposal practices, inherently threaten groundwater and have polluted drinking water sources. Studies from across the United States present irrefutable evidence that groundwater contamination occurs as a result of fracking activities and is more likely to occur close to well pads. In Pennsylvania alone, 343 private drinking water wells have been contaminated or otherwise impacted as the result of drilling and fracking operations over an eight-year period.

Evidence of instances and pathways of water contamination exist even though scientific inquiry is impeded by industry secrecy and regulatory exemptions. The 2005 Energy Policy Act exempts hydraulic fracturing from key provisions of the Safe Drinking Water Act. As a result, fracking chemicals have been protected from public scrutiny as "trade secrets." The oil and gas sector is the only U.S. industry permitted to inject known hazardous materials near, or directly into, underground drinking water aquifers. At the same time, in most states where fracking occurs, routine monitoring of groundwater aquifers near drilling and fracking operations is not required, nor are companies compelled to fully disclose the identity of chemicals used in fracking fluid, their quantities, or their fate once injected underground.

Nevertheless, of the more than 1,000 chemicals that are confirmed ingredients in fracking fluid, an estimated 100 are known endocrine disruptors, acting as reproductive and developmental toxicants, and at least 48 are potentially carcinogenic. Adding to this mix are heavy metals, radioactive elements, brine, and volatile organic compounds (VOCs), which occur naturally in deep geological formations and which can be carried up from the fracking zone with the flowback fluid. A 2020 study identified 1,198 chemicals in oil and gas wastewater, of which 86 percent lack toxicity data sufficient to complete a risk assessment. Between 2012-2022, highly toxic polyfluoroalkyl substances (PFAS or so-called "forever chemicals") were used as ingredients in fracking fluid in more than 9,000 oil and gas wells in multiple states, including New Mexico, Texas, Ohio, Arkansas, Louisiana, Oklahoma, Wyoming, and Pennsylvania.

Toxic substances in the fracking waste stream pose threats to surface water and groundwater. A 2017 study found that spills of fracking fluids and fracking wastewater are common, documenting 6,678 significant spills occurring over a period of nine years in four states alone. In these states, between 2 and 16 percent of wells report spills each year. About five percent of all fracking waste is lost to spills, often during transport. A 2020 survey of groundwater wells in Kern County, California found widespread contamination with wastewater chemicals, including salts, that had leached from both surface pits and underground injection wells. A 2021 study in southeastern New Mexico found that the shift from conventional drilling to fracking was accompanied by dramatic increases in total dissolved solids, sodium, and calcium levels in groundwater aquifers with density of oil wells correlating with concentration of contaminants.

Wastewater spills are not becoming uniformly less frequent with time. Data from the Colorado Oil and Gas Conservation Commission show that the number of gas and oil spills across the state peaked in 2014 and rose again between 2018 and 2019. Fracking operations are depleting groundwater in many arid regions including the Eagle Ford and Permian Basins in Texas.

- May 5, 2023 – In California, unlined surface pits have been used, since the mid-20th century, to hold oil and gas wastewater. The largest number of these impoundments (at least 1,470) are located in the southern portion of the San Joaquin Valley. A comprehensive analysis of the wastewater stored in this way shows that it contains elevated levels of both arsenic and selenium levels and "thus that this disposal practice may have contributed substantial amounts of arsenic and selenium to aquifers." Selenium can rapidly bioaccumulate and thus can find its way into the human food chain via livestock or crops irrigated with wastewater. When wastewater plumes beneath the pits mix, the mobility of any one contaminant can be impeded or potentiated by the presence of another. Further, storing fracking wastewater in unlined evaporation pits increased the concentration of their chemical contaminants. "Our analysis suggests that this disposal practice may have contributed substantial amounts of arsenic and selenium to aquifers" used for agricultural purposes.[631]

- April 12, 2023 – Linked to multiple types of cancer as well as high blood pressure and thyroid disease, per- and polyfluoroalkyl substances (PFAS) are a class of chemicals known for persistence and toxicity at vanishingly low levels. An investigation by researchers from Physicians for Social Responsibility (PSR) found that, since at least 2013, oil and gas companies in New Mexico have used PFAS chemicals as an ingredient in fracking fluid. Gaps in New Mexico's disclosure rules prevent a comprehensive analysis on extent of use, but, using evidence from publicly reported oil and gas industry records, including the industry sponsored FracFocus inventory, the PSR team documented that between 2013 and 2022, oil and gas companies injected more than 200 oil and gas wells in six counties with the PFAS known as Teflon. These wells are located in both the Permian Basin in the southeast corner of the state and the San Juan Basin in the northwest. Oil and gas companies also injected wells in Lea County (in the Permian Basin) with the PFAS called fluoroalkyl alcohol substituted polyethylene glycol. About 80 percent of New Mexicans rely on groundwater for drinking in a state where, in the past decade, gas production has doubled and oil production has increased by a factor of 7. More generally, PSR's investigation revealed that, between 2012 and 2022, oil and gas companies used fracking chemicals in 9,066 oil and gas wells. "Of those wells, the companies injected more than 90 percent with at least one trade secret chemical and more than 40 percent with at least one trade secret surfactant. Some of these trade secret chemicals could be PFAS."[632] [See also entries for February 6, 2023 and September 29, 2022.]

- February 6, 2023 – A PSR research team investigated the use of highly toxic PFAS chemicals in fracking operations in Texas using publicly available but previously unpublicized information. The team found that, since 2013, oil and gas companies used more than 43,000 pounds of PFAS as ingredients in fracking fluids. Gaps in Texas '

[631] Robert J. Rossi et al., "Historic and Contemporary Surface Disposal of Produced Water Likely Inputs Arsenic and Selenium to Surficial Aquifers," *Environmental Science & Technology* 57, no. 19 (May 16, 2023): 7559–67, https://doi.org/10.1021/acs.est.3c01219.
[632] Dusty Horwitt and Barbara Gottlieb, "Fracking with 'Forever Chemicals' in New Mexico" (Physicians for Social Responsibility, April 12, 2023), https://psr.org/wp-content/uploads/2023/04/fracking-with-forever-chemicals-in-new-mexico.pdf.

disclosure rules prevent a full accounting, but, using evidence from publicly reported oil and gas industry records, including the industry sponsored FracFocus inventory, the PSR team documented that "between 2013 and 2022, oil and gas companies injected more than 1,600 oil and gas wells in 73 counties with some 43,000 pounds of the PFAS known as PTFE/Teflon. Oil and gas companies injected 1,222 wells in 66 counties with more than 53,000 pounds of additional chemicals that are PFAS, likely PFAS, or precursor chemicals that could degrade into PFAS... In addition, over the past decade, oil and gas firms fracked 30,700 wells, spread across 171 counties, with at least one trade secret surfactant totaling 331 million pounds. Some of these may be fluorosurfactants."[633] [See also entries for April 12, 2023 and September 29, 2022.]

- February 1, 2023 – Previous research has demonstrated that exposure to fracking wastewater impairs the development and reproduction of the water flea, *Daphnia magna*, a freshwater invertebrate that plays a key role in many aquatic food webs. A research team led by the University of Alberta investigated whether populations of *Daphnia* are able to recover following an acute exposure. In a laboratory experiment that simulated a one-time downstream spill, the team found that low-level exposures to fracking wastewater for 48 hours reduced both reproduction and survivorship of *Daphnia* populations in ways that persisted for at least 19 days post-exposure. In the sample using less concentrated exposure, half of the Daphnia died within five days. In the more concentrated wastewater, nearly 70 percent died. In both cases, those individuals who lived took longer to reach sexual maturity and had fewer offspring. Recovery within a generation did not occur. Proteomic analysis revealed changes in more than 400 proteins, showing that a single short-term exposure had disrupted their metabolism in ways that create persistent harm.[634]

- January 18, 2023 – Although the 2005 Energy Policy Act prevents the federal government from mandating the disclosure of fracking fluid ingredients, 26 states, at various times, have created some transparency with FracFocus, a fracking chemical registry operated by the Ground Water Protection Council. The University of Chicago's Energy Policy Institute evaluated whether such mandated disclosure requirements could make fracking safer by creating public pressure to reduce environmental harms. Using a geocoded database of more than 154,000 wells from 16 states, the team found that disclosure mandates were indeed associated with significant improvements in water quality. "We find that, after the disclosure mandates, operators pollute less per unit of production, use fewer toxic chemicals, and cause fewer spills and leaks." The investigators also showed that water quality improvements after disclosure mandates are

[633] Dusty Horwitt and Barbara Gottlieb, "Fracking with 'Forever Chemicals' in Texas" (Physicians for Social Responsibility, February 6, 2023), https://psr.org/wp-content/uploads/2023/02/fracking-with-forever-chemicals-in-texas.pdf.
[634] Aaron Boyd et al., "Persisting Effects in *Daphnia Magna* Following an Acute Exposure to Flowback and Produced Waters from the Montney Formation," *Environmental Science & Technology* 57, no. 6 (February 14, 2023): 2380–92, https://doi.org/10.1021/acs.est.2c07441.

greater in areas where public pressure is higher, in areas with a greater presence of local environmental groups, and in counties with more local newspapers.[635]

- January 17, 2023 – Abandoned drilling fluids, contaminated with crude oil, salts, and heavy metals, are a large waste stream, and effective treatment of drilling fluid waste is an unsolved problem. A critical review of drilling fluid waste from oil and gas drilling operations around the world examined the environmental fate of drilling fluids after they are discarded. Comparing physical, chemical, and biological technologies for treating this waste, the authors identify limitations with each method. For example, injection into landfills may contain the pollutants but does not remediate them, whereas certain chemical treatments produce secondary pollutants. Biological remediation is slow and requires very specific temperatures, humidity, and pH levels. The problem of how to treat and contain drilling fluid waste is getting worse, not better. "At present, with increases in drilling depth, improvements in drilling technology, and research and development into new drilling fluids, the treatment of drilling fluid waste is becoming increasingly difficult."[636]

- November 8, 2022 – The "Halliburton Loophole" exempts fracking from regulation under the Safe Drinking Water Act (SDWA), which otherwise regulates the underground injection of chemicals. A study of the environmental and economic impacts of the Halliburton Loophole looked at disclosures of chemicals used in fracking operations as reported to the industry sponsored FracFocus inventory, which is managed by an organization of state government officials. The research team found that, between 2014 – 2021, 28 chemicals were used in fracking operations that would otherwise by regulated by the SDWA. Of all disclosures reported to FracFocus, 60-80 percent involved at least one chemical regulated by SDWA, and 19,700 disclosures report using at least one of the regulated chemicals in amounts that exceed the reportable quantity threshold, as defined under the Comprehensive Environmental Response, Compensation, and Liability Act. In total, fracking companies in 23 states reported using 282 million pound of proprietary chemicals that, were it not for the legal exemption, would have been regulated under the SDWA. This problem is getting worse, not better. The research team found that, in 2021, fracking disclosures with at least one chemical that would have been otherwise regulated under SDWA increased to 88 percent, up from 77 percent of disclosures in 2015. "These results show the necessity of a more robust and federally mandated disclosure system and suggest the importance of revisiting exemptions such as the Halliburton Loophole." The top associated supplier of these unregulated chemicals is Halliburton itself.[637]

- November 1, 2022 – A state-by-state inventory of wastewater ("produced water") from oil and gas extraction activities by the Groundwater Protection Council assessed both the

[635] Pietro Bonetti, Christian Leuz, and Giovanna Michelon, "Internalizing Externalities: Disclosure Regulation for Hydraulic Fracturing, Drilling Activity and Water Quality," *SSRN Electronic Journal*, 2023, https://doi.org/10.2139/ssrn.4328692.
[636] Jie Yang et al., "Treatment of Drilling Fluid Waste during Oil and Gas Drilling: A Review," *Environmental Science and Pollution Research*, January 17, 2023, https://doi.org/10.1007/s11356-022-25114-x.
[637] Vivian Underhill et al., "Outcomes of the Halliburton Loophole: Chemicals Regulated by the Safe Drinking Water Act in US Fracking Disclosures, 2014-2021," *Environmental Pollution*, November 2022, 120552, https://doi.org/10.1016/j.envpol.2022.120552.

trend in volumes and the management practices used by operators across different states. The Council found that the production of oil and gas wastewater increased by 6 percent between 2017 and 2021. In the 15-year period between 2007 and 2021, the U.S. production of crude oil increased by 133 percent, natural gas production increased by 70 percent, and the wastewater generated by their extraction rose by 23 percent. The use of evaporation systems to reduce the volume of oil and gas wastewater has grown rapidly, especially in areas prone to earthquakes from deep well injection. The "beneficial reuse" of fracking wastewater is also trending upward. Beneficial reuse includes collecting wastewater and using it to augment fresh water to frack new wells, agricultural irrigation, and dust and ice control on roads. Altogether, in 2021, U.S. oil and gas extraction operations generated 25,860,854,000 barrels of wastewater (1.08 trillion gallons).[638]

- October 31, 2022 – An analysis by the Environmental Data & Governance Initiative of the legal loopholes that have left fracking largely unregulated by the Clean Water Act (CWA) found that 85 chemicals regulated under CWA and totaling nine billion pounds have been used in fracking since 2014. At the same time, an examination of EPA data on violations, inspections, and penalties show that violation rates have been increasing since 2001 while inspection rates have been decreasing. Since 2001, 17.5 percent of oil and gas facilities regulated under CWA's National Pollutant Discharge Elimination System have reported at least one effluent violation. The team concluded that the structure of the CWA itself limits the ability to prevent water contamination from fracking operations. Because fracking relies on underground injection or surface pits to store fracking wastewater, drilling sites do not generally fall under CWA's jurisdiction, which regulates the intentional discharge of wastewater into lakes, rivers or streams. The stormwater permit system, which is the part of the CWA that is designed to prevent unintentionally released stormwater run-off from entering waterways, would otherwise apply. However, the Halliburton Loophole specifically exempts fracking operations from stormwater permitting requirements. Hence, "there is no federal oversight of fracturing activities until there is proof of fracturing contaminants in surface waters."[639]

- October 25, 2022 – A chemical and isotopic analysis of flowback fluids over time from two well pads in the Utica Shale basin in eastern Ohio showed significant variations in composition between the two sites and also over time, with large variability in barium and radium levels. Measurements of some trace chemicals indicated that they were likely produced, or dissolved, by reactions between the injected fracking fluid and the rock formation. These temporal changes in the concentrations and isotopic compositions of chemicals within the fluid indicate that "physical, chemical, or biologically mediated reactions have occurred within the subsurface" during fracking and flowback periods.

[638] ALL Consulting, "U.S. Produced Water Volumes and Management Practices in 2021," November 2022, https://www.gwpc.org/wp-content/uploads/2021/09/2021_Produced_Water_Volumes.pdf.
[639] Vivian Underhill et al., "50 Years After the Clean Water Act, Toxic Chemicals It Regulates Are Still Used in Fracking" (The Environmental Data & Governance Initiative, October 2022), https://envirodatagov.org/wp-content/uploads/2022/10/Fracking-and-the-CWA-report.pdf.

The complex mixture of chemicals used in fracking fluid likely contributes to the evolving composition of chemicals that return to the surface as flowback.[640]

- October 4, 2022 – An Australian team investigated the impact of current and future fracking activities in the Lake Eyre Basin in South Australia, which covers one-sixth of Australia. Lake Eyre is shallow saline lake with no outflow. The rivers of the Lake Eyre Basin remain undammed and free flowing, support vast wetland and floodplain areas in an otherwise arid region, and function as a hotspot for biodiversity. At 50 feet below sea level, its surrounding basin represents the lowest natural point in Australia. The team mapped 831 oil and gas wells in the basin, almost all of which were sited in floodplains. The researchers found that oil and gas production have disrupted flooding regimes, including through roadbuilding and waste storage pits, habitat fragmentation, and flood waters mixing with fracking wastewater. Legislation has remained ineffective in protecting the basin, which is targeted for rapid development with 1,000-1,500 wells being planned for the next 50 years.[641]

- September 29, 2022 – A PSR research team investigated the use of highly toxic PFAS chemicals in fracking operations in Ohio using publicly available but previously unpublicized information. Gaps in Ohio disclosure rules preclude the researchers and the public from understanding how widely the PFAS chemicals have been used, but evidence from publicly reported oil and gas industry records, including the industry-sponsored FracFocus inventory, show that PFAS chemicals were used to frack wells in eight Ohio counties. More generally, the investigation revealed that, between 2013 and 2022, Ohio well operators working in 17 counties claimed at least one fracking chemical as a trade secret in 2,164 oil and gas wells totaling 162 million pounds. The research team also noted that, in addition to exposures from the fracking wells themselves, "Ohioans could be exposed to PFAS through billions of gallons of wastewater from oil and gas wells in Ohio, Pennsylvania, and West Virginia that have been injected into Ohio's 245 underground injection disposal wells, taken to centralized waste treatment facilities, or spread on roads for de-icing or dust suppression." [See also entries for April 12, 2023 and February 6, 2023.][642]

- September 21, 2022 – A geochemical modeling study of 216 water samples collected from private drinking water wells in West Virginia and Ohio found that ten percent were contaminated with at least one chemical contaminant, including arsenic, above the established maximum contaminant level. In this region, fracking operations take place in areas that had historically supported coal mining operations. These activities discharged high concentrations of iron, manganese, sulfate, and toxic metals into local surface waters

[640] Susan A. Welch et al., "Chemical and Isotopic Evolution of Flowback Fluids from the Utica Gas Shale Play, Eastern Ohio USA," *Chemical Geology* 614 (December 2022): 121186, https://doi.org/10.1016/j.chemgeo.2022.121186.
[641] R. T. Kingsford and A. J. D. Walburn, "Oil and Gas Exploration and Development in the Lake Eyre Basin: Distribution and Consequences for Rivers and Wetlands, Including the Coongie Lakes Ramsar Site," *Marine and Freshwater Research*, 2022, https://doi.org/10.1071/MF22063.
[642] Dusty Horwitt and Barbara Gottlieb, "Fracking with 'Forever Chemicals' in Ohio" (Physicians for Social Responsibility, September 29, 2022), https://psr.org/wp-content/uploads/2022/09/fracking-with-forever-chemicals-in-ohio.pdf.

that are hydrologically connected to underlying groundwater. The results show that coal-mining operations have the potential to open pathways of contamination of drinking water supplies. The authors encourage more expansive monitoring programs to evaluate agents of groundwater contamination in regions characterized by complex hydrogeologic conditions where multiple sources of potential contamination are known to exist.[643]

- August 12, 2022 – A Yale research team assessed groundwater vulnerability to contamination from drilling and fracking operations in a region of the Appalachian Basin that includes western Pennsylvania, eastern Ohio, and northern West Virginia. By simulating groundwater flow and contaminant transport, the team identified predictors of vulnerability dependent upon topography, hydrology, and proximity to fracking operations. They estimated that 21,000 – 30,000 people living in this region drink from wells that are vulnerable to contamination from fracking.[644]

- May 26, 2022 – A study conducted by a Pennsylvania State University research team for the Pennsylvania Department of Environmental Protection evaluated the environmental impacts of various dust suppressants used on gravel roads, including wastewater from oil and gas wells. The team found that, oil- and gas-produced wastewater was "essentially no more effective than rainwater" at suppressing dust, likely because of its high concentration of sodium, which does not bind with clay particles. Instead, sodium-rich wastewater application can destabilize dirt and gravel roads and increase long-term road maintenance. Also, wastewater-treated roadbeds showed the highest concentrations of radium in their runoff, sometimes exceeding the standard for radiation in industrial wastewater discharges. Roadbeds treated with OGPWs also produced runoff with high total dissolved solids, chloride, and bromide.[645]

- May 6, 2022 – An American University team of researchers investigated whether drilling and fracking operations have broad regional effects on surface water quality in Appalachia's Marcellus Shale Basin. Noting that the region has long historical ties to two other extractive industries—coal mining and conventional oil and gas drilling—that often co-occur in the same watersheds, the authors assessed whether the density of conventional wells and fracked wells were associated with water quality indices after controlling for coal-mining activity and land cover. They found that conventional well density was linked to higher levels of magnesium and chloride in nearby streams whereas the density of fracked wells was linked to elevated levels of radium 228. The researcher conclude that oil and gas well density in general has "small but measurable effects on

[643] H. G. Siegel et al., "Natural and Anthropogenic Processes Affecting Domestic Groundwater Quality within the Northwestern Appalachian Basin," *Environmental Science & Technology* 56, no. 19 (October 4, 2022): 13761–73, https://doi.org/10.1021/acs.est.2c04011.
[644] Mario A. Soriano, Nicole C. Deziel, and James E. Saiers, "Regional Scale Assessment of Shallow Groundwater Vulnerability to Contamination from Unconventional Hydrocarbon Extraction," *Environmental Science & Technology* 56, no. 17 (September 6, 2022): 12126–36, https://doi.org/10.1021/acs.est.2c00470.
[645] William D. Burgos, "Evaluation of Environmental Impacts from Dust Suppressants Used on Gravel Roads" (Pennsylvania Department of Environmental Protection, Office of Oil and Gas Management, May 26, 2022), https://files.dep.state.pa.us/OilGas/BOGM/BOGMPortalFiles/PADEP_Final_Brine_Report.pdf.

stream water quality; however, the effects of other human activities and land uses, such as coal extraction and urban development, are likely larger."[646]

- February 2, 2022 – A quantitative analysis of chemical contaminants found in liquid waste (produced water) from fracking wells in the Permian Basin identified the presence of mineral salts, metals, oils and grease, volatile and semi-volatile organic compounds, radionuclides, ammonia, hydraulic fracturing additives, and per- and polyfluoroalkyl substances at different concentrations. Chemical compounds were also detected in water samples collected from the Pecos River, which flows through the Permian Basin in New Mexico, but their analysis showed no evidence that they originated from produced water.[647]

- January 26, 2022 – A team led by the University of Toledo chemists used specialized extraction methods to document the presence of many toxic and cancer-causing contaminants in fracking wastewater—including volatile organic compounds, hazardous heavy metals, and radioactive substances. Some of these hazardous contaminants represented chemical additives used in the fracking fluid itself, while others represented contaminants mobilized from the geological fracture zone. In all, the team detected 266 different dissolved organic compounds and 29 elements in the wastewater they assessed, which was collected from the Permian Basin and Eagle Ford formation in Texas.[648]

- January 14, 2022 – A study by a team of researchers in West Virginia investigated the impact of fracking on the microbial communities of nearby streams. Using a two-pronged approach that combined a stream simulation study with a survey of streams with and without nearby fracking operations, the team found that fracking alters stream water temperature, chemistry, CO2 production, and microbial community biodiversity. Changes in light levels and sediment delivery to streams due to deforestation and soil erosion that accompanies the construction of oil and gas infrastructure had a bigger effect on microbial community composition than contamination by wastewater. Deforestation, which allows more light to reach streams, increased the proportion of cyanobacteria and algae in ways that may have cascading effects on stream health.[649]

- December 13, 2021 – The Railroad Commission of Texas allows the discharge of untreated liquid waste from fracking operations into rivers and streams, including within areas designated as agricultural. An analysis of the agency's produced water discharge permits showed that the state allows this waste to be dumped into streams from which cattle drink, if the discharged water quality meets Texas Surface Water Quality Standards

[646] Colin P. Casey et al., "Characterizing the Association between Oil and Gas Development and Water Quality at a Regional Scale," *Freshwater Science* 41, no. 2 (June 1, 2022): 236–52, https://doi.org/10.1086/719983.
[647] Wenbin Jiang et al., "Characterization of Produced Water and Surrounding Surface Water in the Permian Basin, the United States," *Journal of Hazardous Materials* 430 (May 2022): 128409, https://doi.org/10.1016/j.jhazmat.2022.128409.
[648] Ronald V. Emmons et al., "Unraveling the Complex Composition of Produced Water by Specialized Extraction Methodologies," *Environmental Science & Technology* 56, no. 4 (2022): 2334–44, https://doi.org/10.1021/acs.est.1c05826.
[649] Rachel Michaels et al., "Microbial Communities Reveal Impacts of Unconventional Oil and Gas Development on Headwater Streams," *Water Research* 212 (April 2022): 118073, https://doi.org/10.1016/j.watres.2022.118073.

set by the Texas Commission on Environmental Quality for the specific receiving water body. However, the health and environmental effects of these discharges have never been studied nor has a comprehensive risk assessment been undertaken. In addition, evidence found in this study suggests that the lack of communication regarding the identified discharges and the associated water quality "could lead to conflicting groundwater practices that, at least on a local level, could have negative impacts, such as contributing to aquifer overexploitation. This overextraction in turn is expected to negatively impact existing groundwater conservation efforts and the future of water supply of Texas."[650]

- August 20, 2021 – A commentary on new findings that fracking has increased salt concentrations in surfaces waters across the United States (see entry below for August 19, 2021) argues that these results highlight the need to rethink regulatory practices and increase the numbers of chemicals being monitored as salt may be a marker for many other, potentially dangerous chemical contaminants. "A looming question also remains regarding whether the water impacts from [fracking operations] translate into health damages or damages on other measures of well-being. Evidence of…water impacts along with studies of the health impacts of drinking water provide indirect evidence that [fracking-related] water contamination influences health. Direct evidence is needed." The authors advocate for a comprehensive assessment of the health and socio-economic impacts of fracking that uses a common metric grounded in a benefit-cost analysis.[651]

- August 19, 2021 – Using a geocoded database that combines water monitoring with location of fracking operations, a research team found that fracking activity is associated with increases in the salt concentrations of surface waters. In a pattern replicated in multiple shale basins across the United States, the fracking of new wells increased levels of barium, chloride, and strontium in nearby surface waters. Bromide levels were not affected. "We found a robust association between [newly fractured] wells in a watershed and elevated ion concentrations in its surface waters…Our estimates were most pronounced for wells with larger amounts of produced water, wells located over high-salinity formations, and wells closer and likely upstream from water monitors." This study did not attempt to identify the mechanism by which fracking increases water salinity, but the authors highlight a number of likely channels: on-site accidents, including leaks and spills of flowback water from waste pits; brine trucking operations; unauthorized dumping; and long-term leaching through soil after spills occur.[652]

- July 12, 2021 – Using records obtained under the Freedom of Information Act and the FracFocus database of fracking chemical use, an investigation by PSR found that more than 1,200 oil and gas wells in six states were fracked using highly toxic PFAS between 2012 and 2020. These states are Arkansas, Louisiana, Oklahoma, New Mexico, Texas,

[650] Katie Coeckelenbergh et al., "Groundwater Withdrawals Associated with Oil and Gas Production from Water Supply Aquifers in Texas: Implications for Water Management Practices," *Texas Water Journal* 12, no. 1 (December 13, 2021): 151–201, https://doi.org/10.21423/twj.v12i1.7118.
[651] Elaine Hill and Lala Ma, "The Fracking Concern with Water Quality," *Science* 373, no. 6557 (August 20, 2021): 853–54, https://doi.org/10.1126/science.abk3433.
[652] Pietro Bonetti, Christian Leuz, and Giovanna Michelon, "Large-Sample Evidence on the Impact of Unconventional Oil and Gas Development on Surface Waters," *Science* 373, no. 6557 (August 20, 2021): 896–902, https://doi.org/10.1126/science.aaz2185.

and Wyoming. Nicknamed "forever chemicals" because of their inability to break down in the environment or in the bodies of living organisms, PFAS chemicals are linked to cancer, birth defects, high blood pressure during pregnancy, and other health harms. Drinking water is a major route of exposure to PFAS, which were widely used for decades in stain-resistant furniture and carpeting, non-stick cookware, and firefighting foam. In recent years, a growing number of states have set limits on PFAS contaminants in drinking water as evidence showed groundwater contamination from a variety of sources. The PSR investigation revealed that the U.S. Environmental Protection Agency (EPA) scientists reviewed a proposal to use PFAS chemicals as an ingredient in fracking fluid and expressed concerns about human exposures. Despite these concerns, the agency approved the use of these chemicals for fracking in 2011.[653] Researcher and author of the report, Dusty Horwitt, J.D., said in an interview with the *New York Times*, "The EPA identified serious health risks associated with chemicals proposed for use in oil and gas extraction, and yet allowed these chemicals to be used commercially with very lax regulations."[654]

- July 7, 2021 – An investigation by the Center for Biological Diversity found that fracking is widespread in offshore oil and gas extraction operations, 98 percent of which take place in federal waters in the Gulf of Mexico. Fracking companies are permitted to discharge unlimited volumes of fracking waste into the waters of the Gulf. Using data provided to the EPA by the oil industry, researchers determined that an estimated 66.3 million gallons of liquid fracking waste were dumped into the Gulf of Mexico from 2010 through 2020. Toxicity data shows that these discharges can poison fish and other marine life and are likely to do so near offshore wells.[655] [See also entry for October 14, 2020.]

- July 1, 2021 – A U.S. Geological Survey (USGS) study of fracking wastewater in North Dakota aimed to determine whether the geochemical and isotopic fingerprint of fracking wastewater can be used to pinpoint its specific source, should it contaminate drinking water or surface water. The researchers found that the chemical composition of wastewater varies locally across the shale basin. Further, the assumption that wastewater from newly fracked wells would have a different fingerprint than that of wastewater emanating from older wells was not consistently validated by the data. On the other hand, the presence of glycol ethers—which are used as an ingredient in fracking fluid—can help to distinguish fracking wastewater from naturally occurring brine. Also, assessing a specific measure of radioactivity in the form of radium activity ratios would be potentially useful for distinguishing whether the source of the contamination arose from the Bakken or the Three Forks shale formations.[656]

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[653] Dusty Horwitt, "Fracking with 'Forever Chemicals'" (Physicians for Social Responsibility, July 12, 2021), https://www.psr.org/wp-content/uploads/2021/07/fracking-with-forever-chemicals.pdf.
[654] Hiroko Tabuchi, "E.P.A. Approved Toxic Chemicals for Fracking a Decade Ago, New Files Show," *The New York Times*, July 12, 2021, https://www.nytimes.com/2021/07/12/climate/epa-pfas-fracking-forever-chemicals.html.
[655] Center for Biological Diversity, "Toxic Waters: How Offshore Fracking Pollutes the Gulf of Mexico," July 2021, https://www.biologicaldiversity.org/campaigns/fracking/pdfs/Toxic-Waters-offshore-fracking-report-Center-for-Biological-Diversity.pdf.
[656] Gallegos et al., "Insights on Geochemical, Isotopic, and Volumetric Compositions of Produced Water from Hydraulically Fractured Williston Basin Oil Wells."

- June 18, 2021 – Investigating the toxicity of fracking wastewater, a laboratory study exposed larval zebrafish to varying concentrations of sediment mixtures filtered from flowback and produced water from fracking operations. The results showed that, even when removed from the fluid itself, these dissolved solids were toxic to the developing fish. Exposed larva showed alterations in genetic activity, hormone receptor signaling, and antioxidant response. Because toxic sediments settle at the bottom of natural wetlands and can act as a continuous source of contamination, these findings suggest that spills of fracking waste into aquatic ecosystems can create long-term risks for aquatic life.[657] [See also the entry for January 27, 2018.]

- June 1, 2021 – The Oxnard oil field in Ventura County, California—located north of Los Angeles along the state's southern coast—is a large reservoir of oil and tar sands that has been intensely drilled for many decades and is now approaching depletion but remains actively in production. It is also situated within a predominantly agricultural region where crops such as strawberries, onions, and broccoli are grown. The groundwater underlying both the oil fields and the agricultural fields is heavily used and shows signs of contamination by agricultural drainage and seawater intrusion, as well as by upward movement of deeper water into shallower aquifers. A study designed to determine whether water and gases from oil-bearing geological strata had found its way into the groundwater found no evidence of water from oil-bearing strata mixing with overlying groundwater. However, methane and other hydrocarbon gases (ethane, propane, butane, pentane) were detected in five of 14 groundwater samples, and their isotopic fingerprint showed they were not from microbial sources. Further, water samples with the highest concentrations of these gases were near oil wells. Results of this study are consistent with findings of previous studies that revealed the presence of petroleum-related gases in the vicinity of injection wells. The authors conclude that deep formation water is likely to have moved upward due to large groundwater withdrawals in this area.[658]

- April 30, 2021 – A study of deep groundwater aquifers in the Permian Basin of southeastern New Mexico found that the shift from conventional drilling to fracking during the recent shale boom has led to dramatic increases in total dissolved solids, sodium, and calcium levels in groundwater. Also, the density of oil wells correlated with the levels of these substances in the water samples collected.[659]

- April 8, 2021 – Shale formations containing natural gas will, when drilled and fractured, generate large volumes of wastewater that must be disposed of. Some fraction of this wastewater represents fluids and additives used for fracking, and some represents briny water liberated, along with the gas, from the shale formation itself. Using two different screening assays, a laboratory study assessed the toxicity of fracking wastewater over

[657] Yichun Lu et al., "Suspended Solids-Associated Toxicity of Hydraulic Fracturing Flowback and Produced Water on Early Life Stages of Zebrafish (Danio Rerio)," *Environmental Pollution* 287 (2021), https://doi.org/10.1016/j.envpol.2021.117614.
[658] Celia Z. Rosecrans et al., "Groundwater Quality of Aquifers Overlying the Oxnard Oil Field, Ventura County, California," *Science of the Total Environment* 771 (2021), https://doi.org/10.1016/j.scitotenv.2020.144822.
[659] Haoying Wang, "Shale Oil Production and Groundwater: What Can We Learn from Produced Water Data?," *PLoS One* 16, no. 4 (2021), https://doi.org/10.1371/journal.pone.0250791.

time from four wells in the Utica and Marcellus shale regions. The results showed that early-stage flowback fluid was the most toxic and gradually become less toxic as the wells matured. Nevertheless, the acute toxicity specific to certain chemical additives in fracking fluid was still detectable in wastewater up to nine months after hydraulic fracturing. These results support the idea that specific chemical additives, the reactions generated by the additives, or the constituents liberated from the formation by the additives can contribute to the toxicity of hydraulic fracturing wastewater long after the fracking process is finished. The results also affirm the higher toxicity of fracking wastewater from newly fractured wells.[660]

- April 4, 2021 – A methodological study that investigated the effect of fracking on surrounding watersheds developed a protocol to assess the composition of microbial communities in streams as a predictive biomarker for ecological harm from fracking. The researchers suggest gene sequencing of ribosomal RNA as an affordable method for determining bacterial community composition and detail collection methods that allow for an examination of changes in microbial molecular signatures, including genetic expression.[661]

- March 18, 2021 – A study of groundwater geochemistry within Texas' Fort Worth Basin did not find evidence that shallow groundwater was being influenced by the deeper and highly salty water from the intensely fractured Barnett Shale. However, the research team did find geochemical evidence for contamination with methane and other gases that suggest migration from deeper sources to the shallow drinking water aquifers. The researchers reported drinking water wells that were affected by fugitive gas contamination and documented an expansion of impacted drinking water wells over time. The presence of fugitive gases resulted in identifiable geochemical changes in the water, including sulfate reduction paired with microbial oxidation of the fugitive gas. "Together, these data suggest that fugitive gas leads to enhanced microbial activity and decreases in water quality in addition to the explosion hazards associated with a plume of fugitive natural gas in drinking-water wells."[662]

- February 4, 2021 – The city of Akron, Ohio pulled legislation before the city council to lease city-owned land just upstream from the public drinking water reservoir to a private company for drilling and fracking. The company was registered to a local attorney and former city councilmember. Widespread public opposition focused on the need to protect

[660] Mina Aghababaei et al., "Toxicity of Hydraulic Fracturing Wastewater from Black Shale Natural-Gas Wells Influenced by Well Maturity and Chemical Additives," *Environmental Science: Processes & Impacts* 23 (2021): 621–32, https://doi.org/10.1039/D1EM00023C.
[661] Jeremy R. Chen See et al., "Evaluating the Impact of Hydraulic Fracturing on Streams Using Microbial Molecular Signatures," *Journal of Visualized Experiments* 170 (2021), https://doi.org/10.3791/61904.
[662] Colin J. Whyte et al., "Geochemical Evidence for Fugitive Gas Contamination and Associated Water Quality Changes in Drinking-Water Wells from Parker County, Texas," *Science of the Total Environment* 780 (2021), https://doi.org/10.1016/j.scitotenv.2021.146555.

drinking water.[663] The public outcry followed initial approval of the deal on January 12.[664]

- January 15, 2021 – Previous studies have revealed the presence of highly toxic, highly persistent halogenated organic compounds in fracking wastewater, including trihalomethanes, which are known bladder carcinogens. A threat to drinking water, these contaminants are a result of a chemical transformation that takes place when chemical additives in fracking fluids, especially corrosion-inhibitors and substances needed to break apart gels, react with chemicals in the shale itself. A study investigated how halogen radicals so created during these reactions alter the composition of organic chemicals in fracking fluid. The results showed that halogen radicals, such as bromine and chlorine, contribute to the halogenation of additives in fracking fluid. These results provide the first experimental evidence that halogen radicals are the key intermediates in the halogenation of the chemical additives in hydraulic fracturing fluids.[665, 666]

- December 1, 2020 – The Beetaloo Basin in Australia's Northern Territory is targeted for fracking. As part of a pre-drilling environmental assessment of the region and in collaboration with the gas industry, researchers carried out a pilot survey of groundwater wells in the basin and, in the process, discovered 11 new species of shrimp-like and snail-like organisms living in the subterranean aquifers. These stygofauna feed on fungus and microbes in the aquifer and help maintain a complex food web.[667] The researchers who made these discoveries called for the protection of these aquatic habitats. "Groundwater is vital to inland Australia. Underground ecosystems must be protected – and not considered 'out of sight, out of mind.' Our study provides the direction to reduce risks to stygofauna, ensuring their ecosystems and groundwater quality is maintained."[668]

- October 14, 2020 – In January 2015, a pipeline carrying fracking wastewater leaked and spilled into Blacktail Creek near Williston, North Dakota. A study to investigate the longer-term movement of this plume of contaminants was conducted 2.5 years later and found oil and gas wastewater markers consistent with spilled pipeline fluid in bank

[663] Robin Goist, "Akron Pulls Fracking Proposal Following Public Outcry Over Drilling at LaDue Reservoir in Geauga County," Cleveland.com, February 2, 2021, https://www.cleveland.com/akron/2021/02/akron-pulls-fracking-proposal-following-public-outcry-over-drilling-at-ladue-reservoir-in-geauga-county.html.
[664] Doug Livingston, "Akron Wants to Sell Mineral Rights for the Fracking of 475 Acres of Water Shed Land," *Akron Beacon Journal*, January 12, 2021, https://www.beaconjournal.com/story/news/2021/01/12/akron-deal-sells-mineral-rights-drill-and-frack-near-la-due-reservoir/6625435002/.
[665] Moshan Chen et al., "Halogen Radicals Contribute to the Halogenation and Degradation of Chemical Additives Used in Hydraulic Fracturing," *Environmental Science & Technology* 55, no. 3 (2021): 1545–54, https://doi.org/10.1021/acs.est.0c03685.
[666] Moshan Chen et al., "Correction to 'Halogen Radicals Contribute to the Halogenation and Degradation of Chemical Additives Used in Hydraulic Fracturing,'" *Environmental Science & Technology* 55 (2021): 9395–9395, https://doi.org/10.1021/acs.est.1c03216.
[667] Gavin Rees et al., "Characterisation of the Stygofauna and Microbial Assemblages of the Beetaloo Sub-Basin, Northern Territory" (Australia: Commonwealth Scientific and Industrial Research Organisation, 2020), https://gisera.csiro.au/wp-content/uploads/2021/03/GISERA-Project18-Stygofauna_final-report-20201208.pdf.
[668] Jenny Davis et al., "Blind Shrimps, Translucent Snails: The 11 Mysterious New Species We Found in Potential Fracking Sites," *The Conversation*, February 15, 2021, https://theconversation.com/blind-shrimps-translucent-snails-the-11-mysterious-new-species-we-found-in-potential-fracking-sites-155137.

sediments, streambed sediments, and in groundwater seeps. These discoveries imply the existence of potential long-term reservoirs for future contamination, including with radioactivity. Further, the researchers found that the downstream movement of these sediments had also contaminated the alluvial floodplain. They also identified 41 other watersheds across the North Dakota landscape that may be subject to similar episodic inputs from fracking wastewater spills.[669]

- October 14, 2020 – Drilling and fracking operations take place offshore in the Gulf of Mexico where fracking wastewater is also dumped. The mahi-mahi (*Coryphaena hippurus*) is a fast-swimming, predatory fish species that inhabits marine ecosystems where such fracking occurs. An international team of researchers used mahi-mahi fish to study the cardio-respiratory effects of exposure to fracking wastewater. In aquaria studies, they found that exposed organisms displayed reduced swimming speed (40 percent slower) and decreased metabolic rates (61 percent slower). Laboratory studies of individual fish heart muscle cells exposed to diluted concentrations of fracking fluid showed diminished contractile properties. Tissue samples showed an eight-fold change in expression of a gene that regulates contraction of heart muscle was also observed in exposed fish. The team hypothesized that strontium or barium in the wastewater may be the mechanism of action. These results collectively identify cardiac function as a target for fracking wastewater toxicity and provide some of the first published data on the toxicity of fracking for marine fish.[670] These findings tell a cohesive story, according to a companion commentary in *Conservation Physiology*: "Exposure to flowback water caused cardiac abnormalities that resulted in slower-swimming mahi-mahi with less energy available for essential activities."[671]

- September 8, 2020 – A study of the endocrine-disrupting potential of fracking fluid and fracking wastewater examined surface water and groundwater samples across Garfield County, Colorado where fracking operations are densely sited. Using collected surface water and nuclear receptor reporter gene assays, the researcher team observed elevated antagonist activities for estrogen, androgen, progesterone, and glucocorticoid receptors that were associated with nearby shale gas well counts and density. These bioactivities, in some cases were well above the levels known to impact the health of aquatic organisms. They were not, however, associated with reported nearby spills. A geochemical analysis showed that some of these samples exhibited a distinct geochemical pattern that mimicked fracking wastewater from the region. However, the absence of geochemical evidence for fracking wastewater contamination in other sites suggests potential spills of fracking chemicals associated with the freshwater injection fluids, work-over chemicals, or other chemicals used throughout the development and production activities. These findings support earlier research by the same team that documented increased endocrine

[669] Isabelle M. Cozzarelli et al., "Geochemical and Geophysical Indicators of Oil and Gas Wastewater Can Trace Potential Exposure Pathways Following Releases to Surface Waters," *Science of the Total Environment* 755 (2021), https://doi.org/10.1016/j.scitotenv.2020.142909.
[670] Erik J. Folkerts et al., "Exposure to Hydraulic Fracturing Flowback Water Impairs Mahi- Mahi (Coryphaena Hippurus) Cardiomyocyte Contractile Function and Swimming Performance," *Environmental Science & Technology* 54 (2020), https://doi.org/10.1021/acs.est.0c02719.
[671] Lela S. Schlenker, "A Big Fracking Problem Slows Down a Fast-Swimming Fish," *Conservation Physiology* 9 (2021), https://doi.org/10.1093/conphys/coab004.

activities in surface and groundwater collected near fracking sites in Colorado, downstream from an injection site in West Virginia, and downstream from a fracking wastewater spill in North Dakota.[672]

- March 12, 2020 – An international research team investigated the impact of hydraulic fracturing on groundwater in three counties in the intensely drilled Permian Basin in West Texas. The team documented a relationship between intensity of oil and gas activities and levels of groundwater contamination and, in particular, a link between fracking activity and levels of arsenic. The authors noted that "fractures generated by hydraulic fracturing can transport arsenic-rich sediments to upper groundwater aquifers."[673]

- March 2, 2020 – Starting in July 2019, contaminated briny fluid, at the rate of 3 to 5 gallons per minute and then accelerating up to 15 gallons per minute, began bubbling up to the surface on a farm 30 miles northwest of Oklahoma City near eight disposal wells for fracking wastewater. Eight months later, the problem was still ongoing and the cause remained unsolved. The affected farmland has turned brown and barren. In response, three nearby fracking wells were plugged and nearby waste injection wells ceased operations. However, these efforts did not fix the problem nor is there evidence of leaking pipes. State officials are treating the problem as a "purge" of fracking waste linked to too much pressure in the shallow geological formation where companies are injecting it. The president of the Oklahoma Energy Producers Alliance blamed state regulations, put in place as an earthquake prevention measure, that deter drillers from injecting wastes into deeper bedrock. The fracking industry injects 900 billion gallons of wastewater each year into geological formations. As companies run out of room underground to store liquid waste, political pressure is building to allow them to dump the waste into rivers and streams.[674, 675]

- February 28, 2020 – Using data from the Colorado Oil and Gas Conservation Commission, an investigation by the Center for Western Priorities documented a seven percent rise in the frequency of oil and gas industry spills across Colorado in 2019 as compared to the previous year. Half of these spills took place in Weld County, which leads Colorado in drilling. One of these spills, from a ruptured natural gas pipeline, contaminated a creek with benzene. Another 2019 pipeline accident contaminated a

[672] Christopher D. Kassotis et al., "Endocrine Disrupting Activities and Geochemistry of Water Resources Associated with Unconventional Oil and Gas Activity," *Science of the Total Environment* 748 (2020), https://doi.org/10.1016/j.scitotenv.2020.142236.
[673] J. Rodriguez, J. Heo, and K. Kim, "The Impact of Hydraulic Fracturing on Groundwater Quality in the Permian Basin, West Texas, USA," *Water* 12, no. 3 (2020), https://doi.org/10.3390/w12030796.
[674] Karl Torp, "Saltwater Purge Turns Farmland Brown & Barren," *CBS News 9*, March 2, 2020, http://www.news9.com/story/5e627c37cd4aa89d1b92f778/saltwater-purge-turns-farmland-brown--barren.
[675] Mike Soraghan, "Toxic, Briny Water Surfaces in Okla. Is Oil to Blame?," *E&E News*, December 3, 2019, https://web.archive.org/web/20191204112839/https://www.eenews.net/stories/1061708829.

gravel pit near the Colorado River with fracking wastewater.[676] Reported oil and gas industry spills in Colorado peaked in 2014, according to state data.

- February 26, 2020 – A team of chemists at University of Toledo working with counterparts at University of Texas created a method for identifying 201 different chemical compounds in fracking wastewater that can be used to screen for the presence of toxic substances before it is used for agricultural purpose or dumped into waterways. Among the chemicals identified by the team as present in fracking waste were carcinogens and solvents known to contaminate drinking water. These included toluene, polycyclic aromatic hydrocarbons, 1,4-dioxane, and the weed killer atrazine.[677, 678]

- February 17, 2020 – An analysis of historical water use for U.S. fracking operations conducted during a nine-year period in eight major shale basins suggests that water depletion will constrain oil and gas production in the highest producing basins, including the Permian Basin, which, all by itself, accounts for half of all the projected U.S. oil production extracted from shale. Between 2009 and 2017, 73,000 wells with a total lateral length of 134,000 kilometers (83,000 miles) were drilled, and 480 billion gallons of water were used to fracture the shale along that length. The highest water demand is in the semi-arid Permian Basin, which has experienced a sharp growth in water use due both to an increase in the length of the horizontal wells and an increase in water intensity per unit length. The research team found that fracking operations are already depleting groundwater in many arid regions, including the Eagle Ford Shale basin in Texas, where groundwater is also mined for agricultural irrigation. In some cases, the reuse of fracking wastewater to frack new wells can lower demand for new sources of freshwater for fracking. However, regional water scarcity is still anticipated in semi-arid regions where fracking for oil takes place because the projected water demand for fracking operations exceeds the managed available groundwater. In the Permian Basin, where projections of water demand for fracking are the highest, some counties are exceeding planned groundwater depletion over the next 50 years, "suggesting regional water scarcity issues." Also, the extremely high projections for the volume of fracking wastewater in parts of the Permian Basin suggest that fracking may be constrained by lack of capacity in disposal wells. In this region, the reuse of produced water for fracking "may not be sufficient with 4X higher projected produced water volumes than hydrofracking water demand." The problem is not as acute in the humid Marcellus Shale basin where fracking is largely used to extract natural gas. "Among oil plays, the Permian Basin and the Eagle

[676] Dennis Webb, "Oil, Gas Spills Up Statewide. What's the Next Step for the Industry?," *The Daily Sentinel*, April 3, 2020, https://www.gjsentinel.com/news/western_colorado/oil-gas-spills-up-statewide-and-generally-in-piceance/article_d22e128c-5984-11ea-9be1-5336425aef8f.html?fbclid=IwAR3Ts30CLqf3nZrgZWA8-430Kist6-rgP6Gzy8Y6zMxFyuJVeRMMmq57F2U.
[677] Ronald V. Emmons et al., "Optimization of Thin Film Solid Phase Microextraction and Data Deconvolution Methods for Accurate Characterization of Organic Compounds in Produced Water," *Journal of Separation Science* 43, no. 9–10 (2020): 1915–24, https://doi.org/10.1002/jssc.201901330.
[678] Science Codex, "Academic Chemists Note Presence of Chemicals in Fracking Wastewater, Declare Them Toxic at Any Level," University of Toledo, May 26, 2020, https://sciencecodex.com/utoledo-chemists-identify-toxic-chemicals-fracking-wastewater-647887.

Ford plays are regionally vulnerable…. Water scarcity is not likely to be a critical issue in the Bakken as long as there is legal access to water from Lake Sakakawea."[679]

- January 11, 2020 – The 98th meridian, a line of longitude running North to South from eastern North Dakota through the center of Texas, corresponds to a sharp drop-off in rainfall and, ecologically, marks the beginning of the Great Plains. Irrigation is typically required to support agriculture west of the 98th meridian, and livestock grazing is more prevalent. This demarcation also corresponds to an exemption in the National Pollutant Discharge Elimination System: west of the 98th meridian it is permissible to release wastewater from oil and gas extraction activities into rivers and streams for agricultural purposes (irrigation or livestock watering) if it is "of good enough quality." A research team from Colorado State and Pennsylvania State Universities undertook a chemical analysis of a stream in a remote region of Wyoming containing fracking wastewater from multiple wells. They found that most carbon-based contaminants were not detectable beyond 9.3 miles (15 kilometers) of the point of discharge because they had evaporated, biodegraded or became attached to sediments. Some non-carbon-based compounds (strontium, barium, and radium) also gradually decreased in concentration further downstream. Others, however, including sodium, sulfate, and boron, increased further downstream because of water evaporation. These results indicate that "while discharge may be safe, changes downstream could result in water that is unsuitable for beneficial reuse." Multiple organic contaminants, for example, were detected in a shallow downstream lake used by livestock, birds, and wildlife. The health implications of these findings are not clear. First, many of these chemicals have not been assessed for toxicity and lack regulatory limits. Second, mixture effects have not been considered. "Regulatory health thresholds for humans, livestock, and aquatic species for most chemical species present at the discharge are still lacking. As a result, toxicity tests are necessary to determine the potential health impacts to downstream users."[680]

- December 23, 2019 – Using biological assays and liquid chromatography-high resolution mass spectrometry, an interdisciplinary team led by Cornell University researchers analyzed surface and groundwater throughout Susquehanna County, Pennsylvania, specifically focusing on samples collected near Dimock, where fracked gas wells are known to be impaired. The team collected water from private drinking water wells, streams, ponds, springs and a lake. They found that water collected near impaired gas wells showed increased biological activity as measured by alterations of aryl hydrocarbon (Ah) receptor activity in yeast cells, a sign that gene expression has been disrupted. They also found chemicals, including chemical additives known to be present in fracking fluid, associated with samples that were either collected close to impaired wells or that showed either Ah or estrogen receptor activity. In total, the team detected in their water samples 17 potential fracking fluid additives and chemicals associated with fracking wastewater.

[679] Bridget R. Scanlon et al., "Will Water Issues Constrain Oil and Gas Production in the United States?," *Environmental Science & Technology* 54, no. 6 (March 17, 2020): 3510–19, https://doi.org/10.1021/acs.est.9b06390.
[680] Molly C. McLaughlin et al., "Water Quality Assessment Downstream of Oil and Gas Produced Water Discharges Intended for Beneficial Reuse in Arid Regions," *Science of the Total Environment* 713 (2020): 136607, https://doi.org/10.1016/j.scitotenv.2020.136607.

"Although most of these compounds have other uses in addition to natural gas extraction, the association with biological activity and impaired wells suggests that anthropogenic activities, including hydraulic fracturing operations, have resulted in water contamination."[681]

- November 6, 2019 – Oil and gas extraction operations bring to the surface 900 billion gallons of liquid waste every year. In a comprehensive literature review, researchers identified 1,198 chemicals as detected in oil and gas wastewater, of which 86 percent lack toxicity data sufficient to complete a risk assessment.[682]

- September 15, 2019 – A U.S. Geological Survey team working in Kern County, California investigated the migration of wastewater from oil drilling operations into the Tulare aquifer, using geophysical logs archived in state agencies to determine changes in aquifer salinity over time. The study identified two different routes of contaminant migration. The first is downward migration of fluids from unlined wastewater pits through the soil and into the groundwater aquifers below. The second is outward migration of fluids from underground disposal wells into the surrounding aquifers. Contamination from the waste pits was confined to the shallower alluvial aquifer. A clay layer prevents brine from reaching the Tulare aquifer below. Contamination of groundwater from disposal wells in the Tulare formation was detectable as far away as one-third of a mile (1800 feet) from the disposal well.[683]

- July 26, 2019 – Using state-based records, a Mississippi State University geoscientist modeled fracking spills from 2005-2014 in New Mexico and Colorado. In New Mexico, the average volume of fracking-related spill ranged from 3996-5626 gallons and showed no temporal-spatial clustering. In Colorado, average volume of a spill was 1895-3481 gallons, and spills were clustered. The author noted inconsistencies in recordkeeping for fracking-related spills because federal laws require minimal reporting for certain kinds of spills and because, in general, fracking fluid and flowback waste are exempt from federal regulations altogether. Because each state has its own monitoring and reporting system, comparisons are difficult. The requirement for a submitting a spill report often depends on the volume of the spill exceeding a certain threshold value, and that threshold may vary from state to state.[684]

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[681] Michelle Bamberger et al., "Surface Water and Groundwater Analysis Using Aryl Hydrocarbon and Endocrine Receptor Biological Assays and Liquid Chromatography-High Resolution Mass Spectrometry in Susquehanna County, PA," *Environmental Science: Processes & Impacts* 21, no. 6 (2019): 988–98, https://doi.org/10.1039/c9em00112c.
[682] Cloelle Danforth et al., "An Integrative Method for Identification and Prioritization of Constituents of Concern in Produced Water From Onshore Oil and Gas Extraction," *Envonmental International* 134 (2020): 105280, https://doi.org/10.1016/j.envint.2019.105280.
[683] Janice M. Gillespie et al., "Groundwater Salinity and the Effects of Produced Water Disposal in the Lost Hills-Belridge Oil Fields, Kern County, California," *Environmental Geosciences* 26, no. 3 (2019): 73–96, https://doi.org/10.1306/eg.02271918009.
[684] Qingmin Meng, "Characterizing and Modeling Environmental Emergency of Unconventional Oil and Gas Spills in the USA: Life-Year versus Spill Factors," *Journal of Cleaner Production* 237 (2019): 117794, https://doi.org/10.1016/j.jclepro.2019.117794.

- June 27, 2019 – A U.S. Geological Survey team working in the Marcellus Shale region analyzed water samples from private drinking water wells located near shale-gas wells (<1 kilometer) and compared them to wells located further away (>1 kilometer). Using multiple tracers, the team also estimated what fraction of the water in the various wells had been there since 1950. This information, which measures the rate of groundwater recharge, can reveal the vulnerability of well water to contamination from land-surface sources. The results showed the presence of thermogenic methane in one nearby well that appeared to have been mobilized by shale gas drilling. Another nearby well contained five volatile hydrocarbons, including benzene, that are known to be associated with drilling and fracking activities. However, the age of the groundwater predated shale gas development in that area, suggesting that surface spills from drilling and fracking operations were not the source of the contamination. Subsurface leakage from the nearby gas well, however, remains a possibility. "Although vulnerability to land-surface sources of contamination in the Marcellus region is relatively high, the groundwater-age distributions indicate that most of the water in samples from the proximal wells could largely predate [fracking] activity. This suggests that more time is needed to fully assess the effect of past [fracking-related] spills at the land surface on groundwater quality."[685]

- June 24, 2019 – Produced water is the name for wastewater that comes up to the surface from deep geological formations when oil or gas is extracted. Typically salty, produced water includes groundwater naturally found deep in the earth as well as hydrocarbons, radioactive materials, fracking fluids, and other chemicals that were used in the process of extraction. Most produced water is injected into geological layers of porous rock as a form of waste disposal. Some is mixed with fluids used for fracking additional wells. The Groundwater Protection Council, a consortium of state ground water regulatory agencies, released a report on the possibilities of using produced water for beneficial purposes rather than treating it as waste. Driving this discussion is the growing scarcity of fresh water supplies in many drought-prone regions of the United States; the intractable problem of earthquakes when produced water is injected as liquid waste into deep geological formations; and declining storage capacity in shallower formations that are receiving ever-growing quantities of produced water. The Groundwater Protection Council concluded that new regulatory frameworks would need to oversee the recategorization of produced water from waste product to resource for use outside of the oil and gas industry. These frameworks would need to include concerns about ownership and legal liability. "As water becomes scarcer, the increasing benefits of reusing produced water in some regions may outweigh the costs of managing, treating, storing, and transporting it if health and environmental risks can be understood and appropriately

[685] Peter B. McMahon et al., "Hydrocarbons in Upland Groundwater, Marcellus Shale Region, Northeastern Pennsylvania and Southern New York, U.S.A.," *Environmental Science & Technology* 53, no. 14 (n.d.): 8027–35, https://doi.org/10.1021/acs.est.9b01440.

managed." One million oil and gas wells in the United States generate about 21.2 billion barrels of produced water each year.[686, 687, 688]

- June 10, 2019 – A research team from University of Arizona and University of Saskatchewan investigated damage to groundwater from techniques of conventional oil and gas extraction as practiced in both the United States and Canada. These techniques, used since the 19th century, involve injecting water underground to flush out oil and gas--albeit not under pressures high enough to fracture the surrounding rock. The leftover wastewater is eventually disposed of by injecting it into depleted oil fields. The research team found that ten times more water was used in conventional oil and gas extraction than in hydraulic fracturing. While the injection of fluids associated with fracking are of higher pressure, conventional injections are of longer duration and "could allow for greater solute transport distances and potential for contamination." The reinjection of this wastewater has changed underground pressures and the movement of water in ways that can contaminate aquifers. Additionally, conventional wells, when abandoned, can leak and provide further pathways for contamination.[689, 690]

- April 6, 2019 – In a first study of its kind, an international team evaluated the carcinogenicity of chemicals known to be present in both fracking fluids and fracking wastewater. Among 1,173 such chemicals, 1,039 were found only in fracking fluid, 97 only in wastewater, and 37 in both. However, 84.3 percent of the chemicals known to be present in fracking fluid and/or fracking waste have never been assessed for their ability to cause cancer. The researchers found information for only 104 chemicals, of which 48 to 66 are recognized as potential human carcinogens. "Our evaluation suggests that exposure to some chemicals in hydraulic-fracturing fluids and wastewater may increase cancer risk…. Because the amount of each chemical and potential interaction between chemicals in proprietary fracking fluids are unknown, the exact level of cancer-causing potential for exposure to carcinogen-contained fracking fluids is not clear. However, the likelihood of many if not most of the chemical being carcinogenic in large doses or even small doses in fracking fluids is probably high."[691]

- March 28, 2019 – Chemical surfactants are added to fracking fluid to emulsify, reduce surface tension, and inhibit corrosion. An engineering team looked at the chemical fate of

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[686] Ground Water Protection Council, "Produced Water Report: Regulations, Current Practices, and Research Needs" (Ground Water Protection Council, June 2019), https://www.gwpc.org/sites/gwpc/uploads/documents/Research/Produced_Water_Full_Report___Digital_Use.pdf.
[687] Ground Water Protection Council, "Produced Water May Provide Relief for Declining Water Supplies in Areas of the US," Cound Water Protection Council, June 24, 2019, https://www.gwpc.org/news/m.blog/540/produced-water-may-provide-relief-for-declining-water-supplies-in-areas-of-the-us.
[688] Robert Nott, "What to Do With Oil Boom's Wastewater?," *Santa Fe New Mexican*, July 13, 2019, https://www.santafenewmexican.com/news/local_news/what-to-do-with-oil-boom-s-wastewater/article_ebea88d6-ba9d-5e3d-a3eb-0734377fa161.html.
[689] Jennifer C. McIntosh and Grant Ferguson, "Conventional Oil—The Forgotten Part of the Water-Energy Nexus," *Groundwater* 57, no. 5 (2019): 669–77, https://doi.org/10.1111/gwat.12917.
[690] University of Arizona, "Fracking Has Less Impact on Groundwater than Traditional Oil and Gas Production," Phys.org, August 16, 2019, https://phys.org/news/2019-08-fracking-impact-groundwater-traditional-oil.html.
[691] Xiaohui Xu et al., "A Systematic Assessment of Carcinogenicity of Chemicals in Hydraulic-Fracturing Fluids and Flowback Water," *Environmental Pollution* 251 (2019): 128–36, https://doi.org/10.1016/j.envpol.2019.04.016.

these additives when they come back to the surface as shale gas wastewater. They found that high dissolved solids (salts) in the wastewater inhibit microbes that assist in biodegradation. "The presence of higher total dissolved solids appeared to exert an appreciable, long-standing effect on microbial community composition within one week of exposure to increased salinity, suggesting that an accidental release of recycled produced water may upset naturally occurring microbial communities." These results imply that accidental spills of shale gas wastewater—or deliberate releases (as when fracking wastewater is used for de-icing roads or irrigation)—are likely to result in the environmental persistence of these surfactant chemicals. These findings have implications for treating and recycling fracking wastewater. Its high salt levels mean that it must be filtered through special desalinating membranes, but the persistent presence of surfactant chemicals can clog and damage these membranes.[692]

- March 14, 2019 – Rainbow trout exposed to levels of fracking wastewater that mimic those that would result from a low-level spill, as from a pipeline leak into a small river, did not show significant signs of salinity stress. However, their blood plasma did accumulate strontium and bromide. This study did not examine possible endocrine disrupting effects.[693]

- March 5, 2019 – Water fleas (*Daphnia spp.)* are freshwater zooplankton that feed on phytoplankton and play a crucial role in aquatic food webs. In a Canadian study, water fleas exposed to various concentrations of fracking wastewater displayed altered behaviors that impaired their ability to orient toward light, a response that allows them to avoid predation and find food. This study helps explain the results of earlier research that links fracking fluid exposure to decreased water flea survival. Water fleas are unable to detect and avoid fracking fluid spills.[694] (See also entry for April 28, 2018.)

- February 28, 2019 – An American University team compared water quality parameters in 19 small streams in an intensely fracked area of southwestern Pennsylvania with those of 10 equivalent streams in western Maryland where fracking is banned and has never taken place. Streams in both study areas overlie the Marcellus Shale. Even after accounting for variations in forest cover, urban development, and historical impacts from coal mining, the researchers found significant differences in concentrations of certain salts and heavy metals, including arsenic. The results "imply that water quality has been affected by [shale gas] development in the Marcellus Shale region" and "support the idea that the

[692] Andrea J. Hanson et al., "High Total Dissolved Solids in Shale Gas Wastewater Inhibit Biodegradation of Alkyl and Nonylphenol Ethoxylate Surfactants," *Science of the Total Environment* 668 (2019): 1094–1103, https://doi.org/10.1016/j.scitotenv.2019.03.041.
[693] P. L. M. Delompré et al., "The Osmotic Effect of Hyper-Saline Hydraulic Fracturing Fluid on Rainbow Trout, Oncorhynchus Mykiss," *Aquatic Toxicology* 211 (2019): 1–10, https://doi.org/10.1016/j.aquatox.2019.03.009.
[694] P. L. M. Delompré et al., "Shedding Light on the Effects of Hydraulic Fracturing Flowback and Produced Water on Phototactic Behavior in Daphnia Magna," *Ecotoxicology and Environmental Safety* 174 (2019): 315–23, https://doi.org/10.1016./j.ecoenv.2019.03.006.

Pennsylvania streams have received greater pollution inputs than have the Maryland streams."[695]

- February 11, 2019 – The U.S. Justice Department reached a settlement with Antero Resources Corporation over claims that it violated the Clean Water Act at 32 different drilling and fracking-related sites in West Virginia. The violations involved unauthorized dumping of fracking waste into local waterways.[696]

- February 7, 2019 – The Karoo Basin in South Africa is a semi-arid region underlain by gas-containing shale. Its bedrock is also rich in uranium, and, consequently, the basin has a range of different naturally occurring radioactive materials, including radium and radon gas. As part of a baseline study prior to fracking, a South African team monitored the presence of radon in groundwater in 53 aquifers throughout the Karoo Basin. They found that water in seven sites had levels of radon above levels considered safe by the World Health Organization. They also observed lower levels in cool, deep aquifers and higher levels of radon in warm, shallow aquifers, where seasonal and annual fluctuations were common.[697]

- January 22, 2019 – Demand for water to use in fracking operations for oil extraction has more than doubled since 2016, according to data from Rystad Energy, an energy research intelligence company. In the Permian Basin alone, located in west Texas and southeastern New Mexico, water demand for fracking now exceeds the total U.S. demand in 2016.[698]

- January 7, 2019 – From samples of fracking wastewater in Alberta, a Canadian team isolated a previously unidentified class of contaminants, aryl phosphates, which degrade into diphenyl phosphate. Experiments showed that diphenyl phosphate does not bind to clay-rich soils. Therefore, its transportation into groundwater following fracking waste spills would be swift. Further research showed toxic effects of low-level exposure of diphenyl phosphate on fish embryos and embryonic chick tissue. Noting that hundreds of fracking waste spills are reported in Alberta each year, the researchers expressed concern that diphenyl phosphate "may pose an environmental risk to aquatic ecosystems if released into the environment."[699]

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[695] Karen L. Knee and Alexandra E. Masker, "Association Between Unconventional Oil and Gas (UOG) Development and Water Quality in Small Streams Overlying the Marcellus Shale," *Freshwater Science* 38, no. 1 (2019), https://doi.org/10.1086/701675.
[696] Reuters Staff, "U.S. Settles With Antero Over Water Pollution From Fracking," *Reuters*, February 11, 2019, https://www.reuters.com/article/us-usa-antero/us-settles-with-antero-over-water-pollution-from-fracking-idUSKCN1Q021K.
[697] R. Botha et al., "Radon in Groundwater Baseline Study Prior to Unconventional Shale Gas Development and Hydraulic Fracturing in the Karoo Basin (South Africa)," *Applied Radiation and Isotopes* 147 (2019): 7–13, https://doi.org/10.1016/j.apradiso.2019.02.006.
[698] Rystad Energy, "Frac Water Demand Is Sky-Rocketing," press release (Rystad Energy, January 22, 2019), https://www.rystadenergy.com/newsevents/news/press-releases/Frac-water-demand-is-sky-rocketing/.
[699] Sean P. Funk et al., "Assessment of Impacts of Diphenyl Phosphate on Groundwater and Near-Surface Environments: Sorption and Toxicity," *Journal of Contaminant Hydrology* 221 (2019): 50–57, https://doi.org/10.1016/j.jconhyd.2019.01.002.

- November 28, 2018 – Drilling and fracking operations in the Marcellus Shale region are known to harm biodiversity and reduce the populations of aquatic invertebrate animals that are the basis of the food chain in streams. A research team working in West Virginia investigated whether an observed population decline in a species of bird, the Louisiana waterthrush, might be related to loss of these aquatic invertebrates, which are its prey. While the results varied from year to year and loss of food resources did not wholly explain the declines in waterthrush populations in areas of active drilling and fracking, "collective evidence suggests there may be a shale gas disturbance threshold at which waterthrush respond negatively to aquatic prey community changes."[700]

- November 19, 2018 – Methane can find its way into groundwater through naturally occurring fractures and fissures in shale deposits or through openings created by nearby drilling and fracking operations. A team led by Pennsylvania State University geochemist Susan Brantley sampled methane in drinking water wells in Pennsylvania with and without fracking, focusing on an area where fracking wells had been cited for contaminating nearby drinking water wells—in some cases with levels of methane high enough to be at risk for explosion. Researchers found that elevated methane levels in water wells near these fracking operations were accompanied by attendant spikes in iron and sulfates. These findings "document a way to distinguish newly migrated methane from pre-existing sources of gas." They also showed that methane and ethane concentrations in local water wells increased after gas drilling compared with predrilling concentrations and that these levels remained elevated seven years after leaks were initially reported.[701, 702] "We've documented that recent methane migration can change water chemistry in a way that can mobilize metals, such as iron, and release other unwanted chemical compounds, such as hydrogen sulfide," said Joshua Woda, a co-author of the study, in a press statement.[703]

- November 6, 2018 – As reported by the news outlet, *WyoFile*, contaminated drinking water in Pavillion, Wyoming was likely caused by gas leaking from faulty gas wells as well as by leaks from 40 unlined pits that, for many years, served as dumps for drilling wastewater. This was the conclusion of three researchers, including two former U.S. Environmental Protection Agency (EPA) scientists, who had been investigating the pollution of Pavillion's groundwater, including drinking water wells for at least 30 homes. The scientists presented their findings to the community in advance of publishing a peer-reviewed scientific journal article. Statistical analyses show a correlation between

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[700] Mack W. Frantz, Petra B. Wood, and George T. Merovich Jr., "Demographic Characteristics of an Avian Predator, Louisiana Waterthrush (Parkesia Motacilla), in Response to Its Aquatic Prey in a Central Appalachian USA Watershed Impacted by Shale Gas Development," *PLoS One* 13, no. 11 (2018): e0206077, https://doi.org/10.1371/journal.pone.0206077.

[701] Josh Woda et al., "Detecting and Explaining Why Aquifers Occasionally Become Degraded Near Hydraulically Fractured Shale Gas Wells," *Proceedings of the National Academy of Sciences* 115, no. 49 (2018): 12349–58, https://doi.org/10.1073/pnas.1809013115.

[702] Katherine Bourzac, "Chemical Clues Found for Methane Leaks Caused by Fracking," *Chemical & Engineering News*, November 21, 2018, https://cen.acs.org/environment/water/Chemical-clues-found-methane-leaks/96/i47.

[703] Matthew Carroll, "Ground and Stream Water Clues Reveal Shale Drilling Impacts," press release (Penn State News, November 19, 2018), https://news.psu.edu/story/548378/2018/11/19/research/ground-and-stream-water-clues-reveal-shale-drilling-impacts.

what was disposed in the pits and contaminants appearing in nearby drinking water wells. One of the former EPA scientists told community members that the Wind River Formation drinking water aquifer will likely never be cleaned up. A preliminary report from the EPA in 2011 about groundwater contamination in Pavillion was never finalized.[704]

- October 21, 2018 – Fracking brine, among other factors, is contributing to "freshwater salinization syndrome," according to a study that examined the increasing saltiness of North American inland waters. Freshwater salinization, in turn, alters the behavior of other chemicals in water, mobilizing diverse chemical mixtures that alter drinking water quality.[705]

- October 17, 2018 – An international team of researchers tested fracking wastewater from two different wells in the Fox River area of Alberta, Canada for presence of endocrine-disrupting compounds. Using laboratory assays, they found that organic extracts of the wastewater samples did indeed disrupt hormone signaling pathways in environmentally relevant concentrations, as might occur in an accidental spill, however the wastewater from the two different wells did so in two different ways. "The results suggest that the properties and origins of endocrine-disrupting compounds in [fracking wastewater] from Wells A and B are different, complicating our understanding of potential environmental effects of releases."[706]

- September 4, 2018 – Chemicals from fracking wastewater dumped into the Allegheny River Watershed a decade ago are still accumulating in mussels that live there. Researchers working in Pennsylvania found elevated levels of strontium in the shells of freshwater mussels living downstream of a disposal facility that treated fracking wastewater and released it into streams between 2008 and 2011. (The practice was halted thereafter when heavy metals and radioactivity began rising in drinking water). Mussels living upstream of the treatment plant showed no such elevated levels. Strontium is an elemental metal and a contaminant of fracking waste. It is absorbed by living organisms in a similar manner to calcium. Because mussels excrete their shells in discreet layers that can be aged (like tree rings), researchers were able to show that shell layers created after 2011, when dumping of fracking waste into streams had ceased, did not show a sharp reduction in strontium, suggesting that downstream sediments may act as a reservoir for persistent contaminants years after dumping stops.[707] This is one of the first studies to show bioaccumulation of fracking contaminants in the bodies of living animals, which

[704] Angus M. Thuermer Jr., "Pavillion Water Experts Fault Leaky Gas Wells, Unlined Pits," *WyoFile*, November 6, 2018, https://www.wyofile.com/pavillion-water-experts-fault-leaky-gas-wells-unlined-pits/.
[705] Sujay S. Kaushal et al., "Novel 'Chemical Cocktails' in Inland Waters Are a Consequence of the Freshwater Salinization Syndrome," *Philosophical Transactions of the Royal Society B* 374, no. 1764 (2018): 20188017, https://doi.org/10.1098/rstb.2018.0017.
[706] Yuhe He et al., "In Vitro Assessment of Endocrine Disrupting Potential of Organic Fractions Extracted From Hydraulic Fracturing Flowback and Produced Water (HF-FPW)," *Environment International* 121 (2018): 824–31, https://doi.org/10.1016/j.envint.2018.10.014.
[707] Thomas J. Geeza et al., "Accumulation of Marcellus Formation Oil and Gas Wastewater Metals in Freshwater Mussel Shells," *Environmental Science & Technology* 52, no. 18 (2018): 10883–92, https://doi.org/10.1021/acs.est.8b02727.

means that fracking contaminants are entering the food chain. The most endangered of all North American fauna, freshwater mussels are currently suffering a mass extinction event, as a likely result of degraded water quality.[708] Commenting on these findings in a press statement, lead author Nathaniel Warner said, "We know that Marcellus development has impacted sediments downstream for tens of kilometers. And it appears it still could be impacted for a long period of time. The short timeframe that we permitted the discharge of these wastes might leave a long legacy."[709]

- August 29, 2018 – Using reports created by the oil and gas industry, a Colorado State University team evaluated fracking waste spills in Weld County, Colorado and found that while large-scale operations generated less fracking wastewater per unit of energy generated, the total volume of spilled waste increased as the size of the operation increased. "The results suggest that employing fewer, large-scale operators would help reduce the overall volume of [wastewater] generated but not the overall volume spilled." This study also found that the probability of groundwater contamination from those spills was not correlated with either the spill area or with the volume spilled. Instead, the depth to groundwater was a more accurate predictor of the probability of contamination, with shallow water tables at highest risk.[710]

- August 17, 2018 – With 548 permitted wells as of 2017, Belmont County is the most intensely fracked county in the state of Ohio. A Yale University team collected drinking water samples from 66 households in Belmont County that were located at varying distances away from well pads and analyzed them for the presence of fracking-related chemical contaminants. They also interviewed residents about their health symptoms. The primary goal of this exploratory study was to determine whether residential proximity to fracked wells was related to detection and concentrations of health-relevant drinking water contaminants. A second objective was to evaluate possible relationships between proximity to wells and health complaints in the community. The team found that all homes had at least one volatile organic compound or other organic compound above detectable levels and that prevalence of contaminants in drinking water, including toluene, bromoform, and dichlorobromomethane, was higher in homes closer to the wells. Further, people who lived closer to multiple wells were more likely to report health problems including wheezing, stress, fatigue, and headache. This is the first study to concurrently collect drinking water samples, health information, and data on proximity to drilling and fracking operations.[711]

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[708] Kristina Marusic, "Fracking Chemicals Dumped in the Allegheny River a Decade Ago Are Still Showing up in Mussels: Study," *Environmental Health News*, September 5, 2018, https://www.ehn.org/chemicals-from-fracking-in-pennsylvania-polluting-freshwater-mussels-2602333500.html.
[709] Jennifer Matthews, "Fracking Wastewater Accumulation Found in Freshwater Mussels' Shells," *Penn State News*, October 22, 2018, https://news.psu.edu/story/543054/2018/10/22/research/fracking-wastewater-accumulation-found-freshwater-mussels-shells.
[710] Amanda Shores and Melinda Laituri, "The State of Produced Water Generation and Risk for Groundwater Contamination in Weld County, Colorado," *Environmental Science and Pollution Research* 25 (2018): 30390–400, https://doi.org/10.1007/s11356-018-2810-8.
[711] Elise G. Elliott et al., "A Community-Based Evaluation of Proximity to Unconventional Oil and Gas Wells, Drinking Water Contaminants, and Health Symptoms in Ohio," *Environmental Research* 167 (2018): 550–57, https://doi.org/10.1016/j.envres.2018.08.022.

- August 15, 2018 – Using well information from the U.S. Energy Information Agency as well as state-based agencies, a Duke University team examined changes in water use intensity in U.S. drilling and fracking operations as horizontal drilling has evolved toward ever-longer lateral wellbores. They found that water use for fracking operations increased by 770 percent per well between 2011 and 2016 across all U.S. shale basins. At the same time, the volume of fracking wastewater generated during the first year of extraction increased by up to 1,440 percent. "The steady increase of the water footprint of hydraulic fracturing with time implies that future unconventional oil and gas operations will require larger volumes of water for hydraulic fracturing, which will result in larger produced oil and gas wastewater volumes." Noting that the freshwater used for hydraulic fracturing is either retained within the shale formation or returns as highly saline flowback waste that is often subsequently disposed of via deep well injection, the authors concluded that "the permanent loss of water use for hydraulic fracturing from the hydrosphere could outweigh its relatively lower water intensity" compared to other industrial uses of water, such as agriculture, where water is not lost to the hydrological cycle.[712]

- August 5, 2018 – Using water collected from streams and a reservoir near Middletown, Pennsylvania, a research team investigated how contamination with fracking chemicals, as during a spill event, alters the formation of disinfection byproducts when surface water is chlorinated for use as drinking water. They found a shift toward the creation of more brominated compounds. This finding has significant concerns for public health because brominated chemicals are not easily removed during the water treatment process and because discharge of bromide to surface waters remains largely unregulated.[713]

- July 19, 2018 – By simulating spills and discharge of fracking wastewater into rivers and streams, a Pennsylvania research team investigated the effects of fracking wastewater salinity on the creation of disinfection byproducts during drinking water treatment. They found evidence that the ions in salty fracking waste enhance the creation of these deleterious chemicals in ways that conventional water treatment processes cannot easily remove. "Further studies should focus on salinity removal technologies such as reverse osmosis, nanofiltration, electrodialysis, ion exchange, and lime/soda ash softening."[714]

- July 13, 2018 – Chemicals associated with fracking operations have been known to contaminate surface and ground water, and many of them have been identified as endocrine disruptors in mammals, raising questions about possible perturbations of other biological processes, such as immunity. Using tadpoles, an international team investigated how chemicals found in fracking wastewater might affect the developing immune system in amphibians. They found evidence for concern. Even at doses below

[712] Andrew J. Kondash, Nancy E. Lauer, and Avner Vengosh, "The Intensification of the Water Footprint of Hydraulic Fracturing," *Science Advances* 4, no. 8 (2018): eaar5982, https://doi.org/10.1126/sciadv.aar5982.
[713] Kuan Z. Huang, Yuefeng F. Xie, and Hao L. Tang, "Formation of Disinfection By-Products Under Influence of Shale Gas Produced Water," *Science of the Total Environment* 647 (2019): 744–51, https://doi.org/10.1016/j.scitotenv.2018.08.055.
[714] Kuan Z. Huang, Hao L. Tang, and Yuefeng F. Xie, "Impacts of Shale Gas Production Wastewater on Disinfection Byproduct Formation: An Investigation From a Non-Bromide Perspective," *Water Research* 144 (2018): 656–64, https://doi.org/10.1016/j.watres.2018.07.048.

those found in groundwater near spill sites, many exposed tadpoles died. "A first finding of this study is the startling toxicity of the [fracking chemical] mixture to tadpoles…it seems likely that the lethal effect results from the combined activity of some or all of these chemicals." Lower doses significantly altered genes associated with immune functioning and made the developing frogs less able to fight off viral infections. "These findings suggest that [fracking-associated] water pollutants at low but environmentally relevant doses have the potential to induce acute alterations of immune function and antiviral immunity."[715]

- July 4, 2018 – Wastewater samples from a newly fracked oil well in Colorado were examined over 220 days using assays to assess changing toxicity levels. The results revealed significant toxicity throughout well production and during the first 55 days of flowback, with peak toxicity occurring on the first day of flowback. Researchers also looked at the community of microbes (bacteria and archaea) living in the wastewater. Some of these organisms originated from deep in the shale formation and others from the source water used for fracking. These species rapidly changed in relative abundance to one another as the toxicity of the wastewater evolved over time. "Late stage produced water communities gradually became similar to those in the earliest sample of flowback water, indicating that early conditions have a great impact on the resident microbiota over the life of the well."[716]

- June 21, 2018 – A Duke University-led lab study used mouse tissue cultures to investigate possible impacts of fracking wastewater exposure on the development of fat cells. They found that exposure to mixtures of 23 fracking chemicals, as well as raw stream water believed to be contaminated with fracking waste, promoted the growth of fat cells—even at very low concentrations. Collectively, these results show that fracking wastewater has the potential to impair metabolic health at levels found in the environment.[717] In a statement to the media, co-author Chris Kassotis said, "We saw significant fat cell proliferation and lipid accumulation, even when wastewater samples were diluted 1,000-fold from their raw state and when wastewater-affected surface water samples were diluted 25-fold."[718]

- April 28, 2018 – A Canadian study found that the water flea (*Daphnia magna*) becomes immobilized when the surface of test waters are contaminated with fracking waste. This

[715] Jacques Robert et al., "Water Contaminants Associated With Unconventional Oil and Gas Extraction Cause Immunotoxicity to Amphibian Tadpoles," *Toxicological Sciences* 166, no. 1 (2018): 39–50, https://doi.org/10.1093/toxsci/kfy179.
[716] Natalie M. Hull et al., "Succession of Toxicity and Microbiota in Hydraulic Fracturing Flowback and Produced Water in the Denver-Julesburg Basin," *Science of the Total Environment* 10, no. 644 (2018): 183–92, https://doi.org/10.1016/j.scitotenv.2018.06.067.
[717] Christopher D. Kassotis, Susan C. Nagel, and Heather M. Stapleton, "Unconventional Oil and Gas Chemicals and Wastewater-Impacted Water Samples Promote Adipogenesis via PPARy-Dependent and Independent Mechanisms in 3T3-L1 Cells," *Science of the Total Environment* 640–641 (2018): 1601–10, https://doi.org/10.1016/j.scitotenv.2018.05.030.
[718] Tim Lucas, "Exposure to Fracking Chemicals and Wastewater Spurs Fat Cells," Duke.edu, June 21, 2018, https://web.archive.org/web/20180621182703/https://nicholas.duke.edu/about/news/exposure-fracking-chemicals-and-wastewater-spurs-fat-cells.

effect was persistent and occurred at concentrations significantly lower than is required to kill this common zooplankton outright. Immobilized *Daphnia* did not recover after 48 hours, could not feed, and became unable to shed their carapace, thus impeding reproduction. The evidence suggests that surfactants in fracking fluid together with floating hydrocarbons work together to reduce surface tension in ways that disallow *Daphnia* from re-entering the water column. "The current study shows that an important component of the toxicity of [fracking wastewater] to *Daphnia magna* is physical impairment. Depending on how the endpoint of a toxicity test is defined, this mode of action may not be accounted for in laboratory assessments used to determine risk. However, physical toxicity effects are likely to be important in environmental settings where [fracking wastewater] spills may occur."[719] (See also entry for March 5, 2019.)

- April 11, 2018 – A Drexel University team undertook a risk assessment of residential exposures to drinking water contaminated by fracking wastewater (flowback water). This simulation study found that within just eight hours—a realistic timeline for continual exposure due to a spill event—radioactive substances in the wastewater could produce demonstrable risks to human health, especially through the inhalation route. These radioactive compounds posed a greater threat to human health than other contaminants examined in this assessment, including arsenic, benzene, and vinyl chloride. "Radionuclides, which are known to exist in [fracking wastewater] as a result of occurring naturally within shale formations, pose a significant risk to human health and increase the likelihood of developing cancer in exposed individuals…median values for inhalation risk are at unacceptable levels. These exposures are due to the radionuclides aerosolizing from water primarily during showering.… Exposure to certain compounds of flowback water for only a few hours or days…can still present adverse effects."[720]

- April 9, 2018 – An analysis of the bacterial community in 31 northwestern Pennsylvania trout streams showed that fracking activity altered the composition of species found in the sediment. Confirming the findings of previous studies, streams near drilling and fracking activity had significantly higher numbers of methane-metabolizing and methane-producing microorganisms, which are tolerant to acidic conditions. "Altogether, this study highlighted stable bacterial taxa responding to Marcellus shale activity and further supplements a longitudinal correlation of increased acidity of stream water and fracking activity adjacent to headwater streams over five years."[721]

[719] Tamzin A. Blewett et al., "Physical Immobility as a Sensitive Indicator of Hydraulic Fracturing Fluid Toxicity Towards Daphnia Magna," *Science of the Total Environment* 635 (2018): 639–43, https://doi.org/10.1016/j.scitotenv.2018.04.165.
[720] Noura Abualfaraj, Patrick L. Gurian, and Mira S. Olson, "Assessing Residential Exposure Risk from Spills of Flowback Water from Marcellus Shale Hydraulic Fracturing Activity," *International Journal of Environmental Research and Public Health* 15, no. 4 (2018): 727, https://doi.org/10.3390/ijerph15040727.
[721] Nikea Ulrich et al., "Response of Aquatic Bacterial Communities to Hydraulic Fracturing in Northwestern Pennsylvania: A Five-Year Study," *Scientific Reports* 8, no. 1 (2018): 5683, https://doi.org/10.1038/s41598-018-23679-7.

- April 8, 2018 – Working in the South Fork Little Red River watershed in northern Arkansas, a research team found that populations of invertebrate animals were reduced downstream of drilling and fracking operations relative to upstream.[722]

- April 6, 2018 – Chemical characterization and toxicological testing of wastewater from fracked and conventionally drilled oil and gas wells in Pennsylvania were compared. Wastewater from both types of wells was equally toxic to animal and human cells growing in culture and was corrosive at high concentrations. This toxicity was not attributable to the presence of salts alone. Hydrocarbon chemicals were found in both well types and are known to be toxic to multiple human organs. "In vitro assays showed that normal cell survival, behavior, and morphology were severely impaired by short-term exposure to either type of sample at up to 1000-fold dilutions. … Taken together, these results suggest that exposure to leaks or spills associated with either conventional or unconventional oil and gas extraction could potentially impact human health."[723]

- April 5, 2018 – Led by researchers from the University of Missouri, a study conducted in Pavillion, Wyoming compared the effects of water pollution linked to fracking to effects from conventional drilling. Endocrine-disrupting chemicals were found in 22 groundwater samples taken near both kinds of wells. However, the results showed that contaminated groundwater collected near fracking sites was more disruptive to hormonal signaling in human cells than contaminated groundwater collected from conventional well pads. These results corroborate those of past studies.[724] In an associated news story in *WyoFile*, Christopher Kassotis, one of the co-authors of the new study, said, "We have now reported similar endocrine bioactivities across numerous unconventional oil/gas sampling regions, and other researchers are beginning to demonstrate similar effects in cell and animal models. These, above all else, lend strong support for our findings."[725]

- March 5, 2018 – An exemption in the Safe Drinking Water Act allows hydraulic fracturing operations to escape federal regulation, leaving it up to individual states to determine how groundwater resources used for drinking are protected during fracking operations that take place on lands without federal or tribal mineral rights. A research team from Stanford University, University of California, Berkeley, and Lawrence Berkeley National Laboratory assessed these state-based oil and gas regulations in 17 different states. They found that the definitions of "protected groundwater" are vague, inconsistent and, very often, offer less protection than federal regulations. For example, in Alabama and New Mexico, protection of drinking water appears discretionary. In

[722] Bradley J. Austin et al., "Can High Volume Hydraulic Fracturing Effects Be Detected In Large Watersheds? A Case Study of the South Fork Little Red River," *Current Opinion in Environmental Science & Health* 3 (2018): 40–46, https://doi.org/10.1016/j.coesh.2018.04.003.
[723] L. M. Crosby et al., "Toxicological and Chemical Studies of Wastewater From Hydraulic Fracture and Conventional Shale Gas Wells," *Environmental Toxicology* 37, no. 8 (2018): 2098–2111, https://doi.org/10.1002/etc.4146.
[724] Christopher D. Kassotis et al., "Endocrine-Disrupting Activities and Organic Contaminants Associated with Oil and Gas Operations in Wyoming Groundwater," *Archives of Environmental Contamination and Toxicology* 75 (2018): 247–58, https://doi.org/10.1007/s00244-018-0521-2.
[725] Angus M. Thuermer Jr., "Study: Water Near Fracked Wyo Gas Field Disrupts Hormones," *WyoFile*, April 27, 2018, https://www.wyofile.com/study-water-near-fracked-wyo-gas-field-disrupts-hormones/.

Colorado and Texas, protection of drinking water depends on the location of the oil and gas fields. In Illinois, protection during fracking only applies to horizontal wells. In California, drinking water must be monitored but not explicitly protected. Concluding from these findings that the nation's drinking water resources are vulnerable to contamination from oil and gas extraction and wastewater disposal, the research team recommended that criteria defined by the EPA for an underground drinking water source be consistently used to define protected groundwater in state-based oil and gas regulations.[726]

- February 15, 2018 – A UK team used reports from the Texas Railroad Commission (1999-2015) and the Colorado Oil and Gas Conservation Commission (2009-2015) to examine spill rates from oil and gas well pads. They found that the spill rate in both Colorado and Texas significantly increased over the recorded time period, with equipment failure cited as the most common cause. In Colorado, 33 percent of the spills were discovered during site remediation and random site inspections. Using these data, the team predicted that a UK fracking industry would likely experience a spill for every 19 well pads developed.[727]

- January 31, 2018 – Researchers in Arkansas found that water withdrawals for fracking operations can dangerously deplete water levels in up to 51 percent of streams in ways that potentially threaten drinking water supplies, damage aquatic life, and disrupt recreation. "There is potential for these withdrawals to cause water stress," the paper concluded.[728] Water stress represents risk of water scarcity for people caused by increases in economic costs or altered stream flow that results in loss of aquatic biodiversity and ecosystem functioning.

- January 27, 2018 – Fracking wastewater is a developmental toxicant to zebra fish embryos, according to results of a laboratory study conducted by a Canadian team of researchers. Exposure to various concentrations of fracking flowback and produced water, collected from well sites in Alberta, was linked to spinal and heart abnormalities and patterns of altered gene expression consistent with endocrine disruption.[729]

- January 23, 2018 – An Ohio State University team developed and used numerical models to simulate how methane from a leaking well could migrate into different types of drinking water aquifers. Their results showed that rapid, long-distance gas flow was most likely to occur when a pulse of gas under high pressure from a faulty gas well entered

[726] Dominic C. DiGiulio, Seth B. C. Shonkoff, and Robert B. Jackson, "The Need to Protect Fresh and Brackish Groundwater Resources During Unconventional Oil and Gas Development," *Current Opinion in Environmental Science & Health* 3 (2018): 1–7, https://doi.org/10.1016/j.coesh.2018.01.002.
[727] S. A. Clancy et al., "The Potential for Spills and Leaks of Contaminated Liquids From Shale Gas Developments," *Science of the Total Environment* 626 (2018): 1463–73, https://doi.org/10.1016/j.scitotenv.2018.01.177.
[728] Sally Entrekin et al., "Water Stress from High-Volume Hydraulic Fracturing Potentially Threatens Aquatic Biodiversity and Ecosystem Services in Arkansas, United States," *Environmental Science & Technology* 52, no. 4 (2018): 2349–58, https://doi.org/10.1021/acs.est.7b03304.
[729] Yuhe He et al., "Developmental Toxicity of the Organic Fraction from Hydraulic Fracturing Flowback and Produced Waters to Early Life Stages of Zebrafish (Danio Rerio)," *Environmental Science & Technology* 52, no. 6 (2018): 3820–30, https://doi.org/10.1021/acs.est.7b06557.

into a fractured rock aquifer. In these cases, methane can easily migrate a distance of 1 kilometer within a week and in many different directions, including laterally away from the natural gas well. Current efforts to evaluate natural gas leakage from faulty wells "likely underestimate contributions from small-volume, low-pressure leakage events," which require extended periods of environmental monitoring.[730]

- January 16, 2018 – An editorial in the journal *Groundwater* warned researchers against being too quick to dismiss the presence of methane in groundwater near fracking sites as "always naturally occurring," especially in places where no pre-drill baseline data are available or in studies where average methane levels are being compared. Noting that the geological conditions that facilitate the natural migration of hydrocarbons are often "muddled, obfuscating the presence of hydrocarbon pollution due to gas leaking from production wells," the editorial encouraged study designs that make use of odds-ratio tests and geochemical tracers. Fractured rocks within shallow aquifers, in particular, are concerning "both in terms of their potential for facilitating rapid … gas flow, and their inherent geometric complexity, which impact hydrocarbon gas transport mechanisms."[731]

- January 16, 2018 – The Pennsylvania Department of Environmental Protection determined that fracking wastewater that had leaked from a storage pit contaminated groundwater and rendered a natural spring used for drinking water in Greene County undrinkable.[732]

- January 9, 2018 – A University of Texas team collected groundwater samples from across shale basins in Texas and reported on the discovery of opportunistic, pathogenic bacteria in fracking-impacted water wells in Texas. These results raise questions about fracking's effects on the microbial ecology of aquifers. Commenting on their findings, the researchers noted, "The results were quite surprising. Not only did we find that various opportunistic pathogens could survive in the presence of hydrocarbon gases and chemical additives, they appeared to thrive and exhibited robust resistance profiles to multiple antibiotics. We even observed that certain pathogens were resilient to high levels of chlorination."[733]

- December 11, 2017 – A report by the *Texas Observer* investigated groundwater depletion by fracking operations in west Texas at the southern edge of the Ogallala Aquifer. Groundwater conservation districts lack legal financial resources to restrict groundwater pumping or even compel metering on water wells that would monitor exactly how much

[730] Joachim Moortgat, Franklin W. Schwartz, and Thomas H. Darrah, "Numerical Modeling of Methane Leakage from a Faulty Natural Gas Well into Fractured Tight Formations," *Groundwater* 56, no. 2 (2018): 163–75, https://doi.org/10.1111/gwat.12630.
[731] Thomas H. Darrah, "Time to Settle the Fracking Controversy," *Groundwater* 56, no. 2 (2018): 161–62, https://doi.org/10.1111/gwat.12636.
[732] Bob Niedbala, "W.Va. Company Fined $1.7 Million for Violations at 14 Well Sites in Greene County," *Observer-Reporter*, January 17, 2020, https://observer-reporter.com/news/localnews/w-va-company-fined-million-for-violations-at-well-sites/article_cc1ce344-faec-11e7-84ca-076df3832f29.html.
[733] Zacariah Hildenbrand, Ines Santos, and Kevin Schug, "Detecting Harmful Pathogens In Water: Characterizing The Link Between Fracking And Water Safety," *Science Trends*, January 9, 2018, https://sciencetrends.com/detecting-harmful-pathogens-water-characterizing-link-fracking-water-safety/.

water is pumped. In Howard County alone, water used for fracking is now believed to constitute about 20 percent of average annual water use.[734]

- November 16, 2017 – The 2005 Energy Policy Act prohibited the EPA from regulating fracking under the Safe Drinking Water Act and from requiring that operators disclose their chemicals. According to an investigation by *Inside Climate News,* the scientific study that justified this provision (which is widely known as the Halliburton loophole) was the subject of a whistleblower complaint. The study was also disavowed by its authors, who said the conclusion of the report—that fracking posed no risk to groundwater—was not supported by the evidence. These authors removed their names from the final document. Interviewed for the story, one of these authors said that the belief that fracking was safe for water was a foregone conclusion at the EPA under George W. Bush. "What we would have said in the conclusion is that there is some form of risk from hydraulic fracturing to groundwater. How you quantify it would require further analyses, but, in general, there is some risk."[735]

- November 9, 2017 – As part of a preliminary study, a Texas team assessed the groundwater microbiome in a rural area of southern Texas where farming and fracking co-exist. Each of the sampled water wells had a unique community of microorganisms living in the water. The dominant bacteria were denitrifying species that transform nitrates into gaseous nitrogen or those that break apart hydrocarbon molecules. Earlier studies have postulated that fracking can alter the chemical composition of groundwater and change the species composition of the microbial communities living within it. The results of this study "do not provide a definitive link between [fracking] or agricultural activities and the groundwater microbiome; however, they do provide a baseline measurement of bacterial diversity and quantity in groundwater located near these anthropogenic activities."[736]

- November 1, 2017 – In Oklahoma, horizontal wells can be fracked within 600 feet of older, vertical wells that do not use fracking. Oil companies in Oklahoma that extract oil using conventional, vertical wells alleged that hundreds of their wells have been inundated by fluids from nearby horizontal wells that use high-volume hydraulic fracturing, as documented by *E&E News*. Vertical well operators have raised questions about whether these "frack hits" from nearby horizontal wells that have flooded their own wells have also reached the groundwater. "Logic said it will impact [groundwater]," said one driller. "There was water coming up out of the ground. There was enough pressure to bring it to the surface." Small operators of vertical wells, organized as the Oklahoma Energy Producers Alliance (OEPA), released a study estimating that, in just one county

[734] Christopher Collins, "Big Spring vs. Big Oil," *The Texas Observer*, December 11, 2017, https://www.texasobserver.org/big-spring-vs-big-oil/.
[735] Neela Banerjee, "Industrial Strength: How the U.S. Government Hid Fracking's Risks to Drinking Water," *Inside Climate News*, November 16, 2017, https://insideclimatenews.org/news/16112017/fracking-chemicals-safety-epa-health-risks-water-bush-cheney.
[736] Ines C. Santos et al., "Exploring the Links Between Groundwater Quality and Bacterial Communities Near Oil and Gas Extraction Activities," *Science of the Total Environment* 618 (2018): 165–73, https://doi.org/10.1016/j.scitotenv.2017.10.264.

alone, there were 400 cases of frack fluid from horizontal wells flooding nearby vertical wells.[737, 738]

- October 31, 2017 – A study of fracking wastewater disposed of in rivers and streams found that chemical contaminants in the waste were transformed into more toxic substances when they chemically reacted with chlorinated compounds discharged from downstream drinking water treatment plants. The result was dozens of different, brominated and iodinated disinfection byproducts (DBPs). A lab analysis found that all were highly toxic to mammalian cells. Conventional water treatment practices do not remove these chemicals. "It is likely that in oil- and gas-impacted drinking water sources, iodo-phenolic DBPs could form at significant levels, particularly in cases in which chloramination is used."[739]

- October 18, 2017 – Researchers concerned about reports of skin rashes, gastrointestinal distress, and breathing problems among people who live near drilling and fracking operations found increased levels of certain harmful bacteria in private water wells impacted by fracking in the Barnett and Eagle Ford Shale areas in Texas. These results raise questions about whether drilling and fracking activities could alter the communities of microorganisms in groundwater in ways that pose health risks. According to one of the lead authors of the study, interviewed in the *Dallas News*, "the potential contribution of these microbes to these health effects is probably understudied, underappreciated, unknown."[740, 741]

- August 3, 2017 – Due to permitting errors and a mix-up in records 30 years ago, wastewater from drilling operations in California was mistakenly injected directly into drinking water aquifers. Six years after the discovery of the problem, 175 wastewater wells that were illegally injecting into protected aquifers have been shut down, but hundreds more are still operating. An investigation by KQED Science revealed that California state water regulators know very little about the actual impact of those injections on the state's drinking water reserves. "State water regulators say they hope to figure out what the larger impacts have been in years ahead, but have no set timeline. The risk is that they've allowed oil companies to contaminate drinking water aquifers to such

[737] Mike Soraghan, "Now It's Oilmen Who Say Fracking Could Harm Groundwater," *E&E News*, November 1, 2017, https://web.archive.org/web/20171101181846/https://www.eenews.net/stories/1060065209.
[738] OEPA, "Are Vertical Wells Impacted by Horizontal Drilling? A Study of Kingfisher County" (OEPA, September 14, 2017), https://www.eenews.net/assets/2017/10/27/document_pm_07.pdf.
[739] Hannah K. Liberatore et al., "Identification and Comparative Mammalian Cell Cytotoxicity of New Iodo-Phenolic Disinfection Byproducts in Chloraminated Oil and Gas Wastewaters," *Environmental Science & Technology Letters* 4, no. 11 (2017): 475–80, https://doi.org/10.1021/acs.estlett.7b00468.
[740] Misty S. Martin et al., "Characterization of Bacterial Diversity in Contaminated Groundwater Using Matrix-Assisted Laser Desorption/Ionization Time-of-Flight Mass Spectrometry," *Science of the Total Environment* 622–623 (2018): 1562–71, https://doi.org/10.1016/j.scitotenv.2017.10.027.
[741] J. Mosier, "UTA Research Finds Dangerous Bacteria in Groundwater Near Texas Gas Drilling Sites.," *Dallas News*, December 1, 2017, https://www.dallasnews.com/business/energy/2017/12/01/uta-study-finds-dangerous-bacteria-groundwater-near-texas-gas-drilling-sites.

an extent that Californians may have permanently lost those sources of fresh water."[742] An earlier investigation by KQED Science revealed that illegal wastewater wells would still be allowed to operate while the necessary paperwork was filed.[743]

- July 12, 2017 – In western Pennsylvania, a team of researchers looked at sediments in the Conemaugh River watershed downstream of a treatment plant that was specially designed to treat fracking wastewater. The researchers found contamination for many miles downstream with fracking-related chemicals that included radium, barium, strontium, and chloride, as well as endocrine-disrupting and carcinogenic compounds. The peak concentrations were found in sediment layers that had been deposited during the years of peak fracking wastewater discharge. Elevated concentrations of radium were detected as far as 12 miles downstream of the treatment plant and were up to 200 times greater than background. Some stream sediment samples were so radioactive that they approached levels that would, in some U.S. states, classify them as radioactive waste and necessitate special disposal.[744, 745]

- May 31, 2017 – A USGS team sampled drinking water wells near drilling and fracking sites in the Eagle Ford, Fayetteville, and Haynesville Shale basins and found detectable levels of methane and benzene. However, the sources of these contaminants were unclear, and, given the slow travel time of groundwater, "decades or longer may be needed to fully assess the effects of potential subsurface and surface releases of hydrocarbons on the wells."[746]

- May 1, 2017 – A study examining the impacts of drilling and fracking operations on public drinking water in Pennsylvania found evidence of contamination when drinking water source intakes were located within one kilometer (.62 miles) of a well pad. Noting that many Pennsylvanians living near well pads drink bottled water, the authors concluded, "our results suggest that these perceived risks may in fact be justified."[747] (See also entry below for October 13, 2016.)

[742] Lauren Sommer, "How Much Drinking Water Has California Lost to Oil Industry Waste? No One Knows," *KQED Science*, August 3, 2017, https://www.kqed.org/science/1914130/how-much-drinking-water-has-california-lost-to-oil-industry-waste-no-one-knows.
[743] Lauren Sommer, "California Says Oil Companies Can Keep Dumping Wastewater During State Review," *KQED Science*, January 17, 2017, https://www.kqed.org/science/1330777/california-says-oil-companies-can-keep-dumping-wastewater-during-state-review.
[744] William D. Burgos et al., "Watershed-Scale Impacts from Surface Water Disposal of Oil and Gas Wastewater in Western Pennsylvania," *Environmental Science & Technology* 51, no. 15 (2017): 8851–60, https://doi.org/10.1021/acs.est.7b01696.
[745] Ian Johnston, "Fracking Can Contaminate Rivers and Lakes With Radioactive Material, Study Finds," *The Independent*, July 12, 2017, http://www.independent.co.uk/news/science/fracking-dangers-environment-water-damage-radiation-contamination-study-risks-a7837991.html.
[746] Peter B. McMahon et al., "Methane and Benzene in Drinking-Water Wells Overlying the Eagle Ford, Fayetteville, and Haynesville Shale Hydrocarbon Production Areas," *Environmental Science & Technology* 51, no. 12 (2017): 6727–34, https://doi.org/10.1021/acs.est.7b00746.
[747] Elaine Hill and Lala Ma, "Shale Gas Development and Drinking Water Quality," *American Economic Review: Papers & Proceedings* 107, no. 5 (2017): 522–25, https://doi.org/10.1257/aer.p20171133.

- April 19, 2017 – Using data from the South Coast Air Quality Monitoring District, a team of researchers in California compared chemicals used in fracking operations with those used in the routine maintenance of conventional oil and gas wells where chemicals are used to aid in drilling, for corrosion control, to clean the wellbore, and to enhance oil recovery. They found significant overlap in both the types and amounts of chemicals used. "The results of this study indicate regulations and risk assessments focused exclusively on chemicals used in well-stimulation activities may underestimate potential hazard or risk from overall field chemical-use. . . . Our analysis shows that hydraulic fracturing is just one of many applications of hazardous chemicals on oil and gas fields."[748]

- April 5, 2017 – A three-year study in West Virginia led by scientists at Duke University assessed surface water and groundwater drawn from drinking water wells both before and after drilling and fracking began in the region. Using geochemical techniques, including a suite of tracers that help distinguish naturally occurring methane and salts from those contained in fracking fluid, the researchers found no evidence of groundwater contamination. They did, however, document threats to surface water from fracking wastewater spills.[749] In an accompanying statement, the researchers noted, "What we found in the study area in West Virginia after three years may be different from what we see after 10 years because the impact on groundwater isn't necessarily immediate."[750]

- Feb 21, 2017 – Between 2005 and 2014, researchers surveyed spill record data from drilling and fracking operations in four states (Colorado, New Mexico, North Dakota, and Pennsylvania). During these nine years, they documented 6,678 total spills, or about five spills each year for every 100 wells. Between 2 and 16 percent of wells reported a spill each year. Half of all spills were related to storage and transport of fluids through flow lines. The authors also found that the chances of spills are highest during the first three years of a well's life and that spill reporting requirements differ markedly from state to state, making impossible the task of comparing states or creating a national picture.[751, 752]

- January 31, 2017 – California is the only state that allows fracking waste to be held in unlined, open pits, creating risks for groundwater contamination. A California Water

[748] William T. Stringfellow et al., "Comparison of Chemical-Use Between Hydraulic Fracturing, Acidizing, and Routine Oil and Gas Development," *PLoS ONE* 12, no. 4 (2017): e0175344, https://doi.org/10.1371/journal.pone.0175344.
[749] Harkness, J. S. et al., "The Geochemistry of Naturally Occurring Methane and Saline Groundwater in an Area of Unconventional Shale Gas Development," *Geochimica et Cosmochimica Acta* 208 (2017): 302–34, https://doi.org/10.1016/j.gca.2017.03.039.
[750] Tim Lucas, "West Virginia Groundwater Not Affected by Fracking, but Surface Water Is," Duke.edu, April 24, 2017, https://nicholas.duke.edu/news/west-virginia-groundwater-not-affected-fracking-surface-water.
[751] Lauren A. Patterson et al., "Unconventional Oil and Gas Spills: Risks, Mitigation Priorities, and State Reporting Requirements," *Environmental Science & Technology* 51, no. 5 (2017): 2563–73, https://doi.org/10.1021/acs.est.05749.
[752] Nicholas Kusnetz, "Fracking Well Spills Poorly Reported in Most Top-Producing States, Study Finds," *Inside Climate News*, February 21, 2017, https://insideclimatenews.org/news/21022017/fracking-spills-north-dakota-colorado.

Boards investigation found that, as of January 2017, 1,000 such pits were operational, with 400 lacking required state permits. The vast majority is located in Kern County.[753]

- December 14, 2016 – To better understand the impact of fracking fluid spills on aquatic animals, scientists at the University of Alberta exposed rainbow trout in laboratory tanks to various dilutions of fracking fluids. Even at very low exposures, the fish experienced adverse effects, including alterations in liver functioning and disruption of hormonal pathways. [This study was partially funded by industry.][754]

- December 13, 2016 – The final version of the EPA's six-year, $29 million study on the impacts of hydraulic fracturing on the nation's drinking water confirmed that fracking activities have caused contamination of water resources in the United States, and it traced the various routes by which drinking water can be impacted by fracking. Documented cases of drinking water contamination have resulted from spills of fracking fluid and fracking wastewater; discharge of fracking waste into rivers and streams; and underground migration of fracking chemicals, including gas, into drinking water wells. Depletion of aquifers caused by water withdrawals has created other impacts.[755, 756, 757, 758] The final EPA report detailed the problem of fracking-related drinking water contamination in three communities—Pavillion, Wyoming; Dimock, Pennsylvania; and Parker County, Texas.[759] Summing up the report, then-EPA Deputy Administrator Tom Burke said in a statement to *American Public Media*, "We found scientific evidence of impacts to drinking water resources at each stage of the hydraulic fracturing cycle."[760] (See also the entry for June 5, 2015, which describes the contents of the 2015 draft report.)

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[753] California Water Boards, "Produced Water Pond Status Report" (California Water Boards, January 31, 2017), https://www.waterboards.ca.gov/water_issues/programs/groundwater/sb4/docs/pond_rpt_0117_fnl.pdf.
[754] Yuhe He et al., "Effects on Biotransformation, Oxidative Stress and Endocrine Disruption in Rainbow Trout (Oncorhynchus Mykiss) Exposed to Hydraulic Fracturing Flowback and Produced Water," *Environmental Science & Technology* 51, no. 2 (2017): 940–47, https://doi.org/10.1021/acs.est.6b04695.
[755] U. S. Environmental Protection Agency, "EPA's Study of Hydraulic Fracturing for Oil and Gas and Its Potential Impact on Drinking Water Resources," 2016, https://www.epa.gov/hfstudy.
[756] U. S. Environmental Protection Agency, "EPA's Study of Hydraulic Fracturing for Oil and Gas: Impacts From the Hydraulic Fracturing Water Cycle on Drinking Water Resources in the United States," Appendices (U. S. Environmental Protection Agency, 2016), https://www.epa.gov/hfstudy/hydraulic-fracturing-study-fact-sheets.
[757] U. S. Environmental Protection Agency, "EPA's Study of Hydraulic Fracturing and Its Potential Impact on Drinking Water Resources," Executive Summary (U. S. Environmental Protection Agency, 2016), https://www.epa.gov/hfstudy/executive-summary-hydraulic-fracturing-study-final-assessment-2016.
[758] Scott Tong and T. Scheck, "EPA's Late Changes to Fracking Study Downplay Risk of Drinking Water Pollution," *Marketplace*, November 30, 2016, https://www.marketplace.org/2016/11/29/world/epa-s-late-changes-fracking-study-portray-lower-pollution-risk.
[759] U. S. Environmental Protection Agency Science Advisory Board, "SAB Review of the EPA's Draft Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources" (EPA-SAB, August 11, 2016), https://yosemite.epa.gov/sab/sabproduct.nsf/LookupWebReportsLastMonthBOARD/BB6910FEC10C01A18525800C00647104/$File/EPA-SAB-16-005+Unsigned.pdf.
[760] Tom Scheck and Scott Tong, "EPA Reverses Course, Highlights Fracking Contamination of Drinking Water," *APM Reports*, December 13, 2016, https://www.apmreports.org/story/2016/12/13/epa-fracking-contamination-drinking-water.

- December 1, 2016 – According to a review paper that examines the potential environmental impacts of oil and gas wastewater, about 5 percent of fracking waste is accidentally or illegally spilled. Almost all of the rest is transported off site and injected into disposal wells that are drilled into porous geological formations. In North Dakota's Bakken Shale, disposal wells are located within miles of the well pad, and the wastewater can travel there via pipeline. In Pennsylvania's Marcellus Shale, drilling activity exceeds the capacity for disposal of waste in local wells and must be trucked out of state.[761]

- November 4, 2016 – A critical review of potential routes of water contamination from drilling and fracking operations in the Bakken Shale noted that the high salinity of fracking wastewater minimizes its recycling options and thus contributes to the need for disposal wells. Transportation of large volumes of waste to these wells, via truck or pipeline, presents opportunities for large spills that can threaten groundwater.[762]

- October 16, 2016 – A team of scientists led by researchers at the Lawrence Berkeley National Laboratory evaluated chemicals used for fracking in California oil fields. Chemical additives included a wide variety of solvents in large amounts, as well as other toxic substances, including biocides and corrosion inhibitors.[763]

- October 14, 2016 – One of the first studies to investigate the impacts of fracking on the ecology of streams found that fracking "has the potential to alter aquatic biodiversity and methyl mercury concentrations at the base of food webs." The researchers sampled 27 remote streams in the Marcellus Shale basin of Pennsylvania where drilling and fracking is taking place. They showed that methyl mercury levels in stream sites where fracking occurs were driven upwards by higher acidity and lower numbers of macroinvertebrates. In streams with the highest numbers of fracking fluid spills, "fish diversity was nil," and in some cases, there were no fish at all, including in streams previously classified as high-quality brook trout habitat. "Fracking and flowback fluids can contain various highly acidic agents, organic and inorganic compounds, and even Hg [mercury]. The flowback fluids can reach nearby streams through leaking wastewater hoses, impoundments, and lateral seepage and blowouts, as well as by backflow into the wellhead. Flowback water reaching streams can . . . decrease aquatic biodiversity. . . . Lowered stream pH increases Hg solubility, leading to increased bioaccumulation in food webs."[764]

- October 13, 2016 – Researchers at Pennsylvania State University and Ohio State University combined GIS data on drilling and fracking activities in Pennsylvania and Ohio with household data on bottled water purchases. They found that yearly household purchases of bottled water increased as local drilling and fracking intensity increased.

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[761] Lindsey Konkel, "Salting the Earth: The Environmental Impact of Oil and Gas Wastewater Spills," *Environmental Health Perspectives* 124, no. 12 (2016): A230–35, https://doi.org/10.1289/ehp.124-A230.
[762] Namita Shrestha et al., "Potential Water Resource Impacts of Hydraulic Fracturing From Unconventional Oil Production in the Bakken Shale," *Water Research* 108 (2017): 1–24, https://doi.org/10.1016/j.watres.2016.11.006.
[763] William T. Stringfellow et al., "Identifying Chemicals of Concern in Hydraulic Fracturing Fluids Used for Oil Production," *Environmental Pollution* 220, Pt A (2017): 413–20, https://doi.org/10.1016/j.envpol.2016.09.082.
[764] Christopher James Grant et al., "Fracked Ecology: Response of Aquatic Trophic Structure and Mercury Biomagnification Dynamics in the Marcellus Shale Formation," *Ecotoxicology* 25 (2016): 1739–50, https://doi.org/10.1007/s10646-016-1717-8.

This "averting behavior" is a measure of perceived risk. In 2010, averting-behavior expenditures in the form of bottled water purchases by people living in Pennsylvania's shale counties totaled $19 million.[765] (A subsequent study suggests that those engaged in tapwater averting behaviors in Pennsylvania have evidence-based reasons to be concerned. See entry above, for May 1, 2017.)

- September 22, 2016 – Using the agency's list of 1076 chemicals that have reported use as ingredients in hydraulic fracturing fluid, EPA scientists developed a framework to analyze and rank subsets of chemicals in order to better understand which fracking-related chemicals pose the greatest risk to drinking water. Their model collates multiple lines of evidence. For example, data on inherent toxicity are combined with data on occurrence and propensity for environmental transport. In the absence of local data on actual human exposures, this model can serve as a qualitative metric to "identify chemicals that may be more likely than others to impact drinking water resources."[766]

- September 16, 2016 – A reconnaissance analysis of groundwater in the Eagle Ford Shale region in southern Texas found sporadic detections of multiple VOCs and dissolved gas, providing evidence that "groundwater quality is potentially being affected by neighboring [drilling and fracking] activity, or other anthropogenic activities, in an episodic fashion." The authors called for a more extensive investigation of possible groundwater contamination in the Eagle Ford basin.[767, 768]

- July 11, 2016 – An interdisciplinary team led by University of Colorado researchers found methane in 42 water wells in the intensely drilled Denver-Julesburg Basin where high volume, horizontal fracking operations began in 2010. By examining isotopes and gas molecular ratios, the researchers determined that the gas contaminating these wells was thermogenic in origin, rather than microbial, and therefore had migrated up into the groundwater from underlying oil- and gas-containing shale. The steady rate of well contamination over time—two cases per year from 2001 to 2014—suggests that well failures, rather than the process of hydraulic fracturing itself, was the mechanism that created migration pathways for the stray gas to reach drinking water sources. Of the 42 affected wells, 11 had already been identified by state regulators as suffering from "barrier failures."[769] Duke University geochemist Avner Vengosh, who was not an author

[765] Douglas H. Wrenn, H. Allen Klaiber, and Edward C. Jaenicke, "Unconventional Shale Gas Development, Risk Perceptions, and Averting Behavior: Evidence from Bottled Water Purchases," *Journal of the Association of Environmental and Resource Economists* 3, no. 4 (2016).
[766] Erin E. Yost, John Stanek, and Lyle D. Burgoon, "A Decision Analysis Framework for Estimating the Potential Hazards for Drinking Water Resources of Chemicals Used in Hydraulic Fracturing Fluids," *Science of the Total Environment* 574 (2016): 1544–58, https://doi.org/10.1016/j.scitotenv.2016.08.167.
[767] Zacariah L. Hildenbrand et al., "A Reconnaissance Analysis of Groundwater Quality in the Eagle Ford Shale Region Reveals Two Distinct Bromide/Chloride Populations," *Science of the Total Environment* 575 (2017): 672–80, https://doi.org/10.1016/j.scitotenv.2016.09.070.
[768] Zacariah L. Hildenbrand et al., "Corrigendum to 'A Reconnaissance Analysis of Groundwater Quality in the Eagle Ford Shale Region Reveals Two Distinct Bromide/Chloride Populations,'" *Science of the Total Environment* 603 (2017): 834–35, https://doi.org/10.1016/j.scitotenv.2017.05.200.
[769] Owen A. Sherwood et al., "Groundwater Methane in Relation to Oil and Gas Development and Shallow Coal Seams in the Denver-Julesburg Basin of Colorado," *Proceedings of the National Academy of Sciences* 113, no. 30 (2016): 8391–96, https://doi.org/10.1073/pnas.1523267113.

of the paper, commented on the study in an accompanying article in *Inside Climate News*: "The bottom line here is that industry has denied any stray gas contamination: that whenever we have methane in a well, it is always preexisting. The merit of this is that it's a different oil and gas basin, a different approach, and it's saying that stray gas could happen." In this same article, *Inside Climate News* reported that national standards for well construction do not exist, nor are there laws governing the type of cement that is used to seal the wellbore and prevent leaks.[770]

- May 24, 2016 – ATSDR conducted a public health evaluation using groundwater data gathered in 2012 by the EPA from 64 private drinking water wells in Dimock, Pennsylvania where natural gas drilling and fracking activities began in 2008 and where residents began reporting problems with their water shortly thereafter. The agency found that water samples collected from 27 Dimock wells contained contaminants "at levels high enough to affect human health." These included methane, salts, organic chemicals, and arsenic. In 17 wells, levels of methane were high enough to create risk of fire or explosion.[771] Methane levels were not assessed in wells prior to the start of fracking activities in the area. Hence, the study is limited by lack of pre-drilling baseline data, and investigators did not attempt to determine the source of the contaminants. However, in its focus on identifying health impacts, ATSDR's evaluation is a more comprehensive study than that conducted four years earlier by the EPA and calls into question its earlier, more reassuring conclusions.[772, 773]

- May 9, 2016 – Sampling downstream of a fracking wastewater disposal facility in West Virginia, a USGS team documented changes in microbial communities and found evidence indicating the presence of fracking waste in water and sediment samples collected from Wolf Creek in West Virginia. Specifically, the researchers documented increased concentrations of barium, bromide, calcium, sodium, lithium, strontium, iron, and radium downstream of the disposal well.[774] In a *Washington Post* story about this study, lead author Denise Akob said that the key take-away message "is really that we're demonstrating that facilities like this can have an environmental impact."[775] (This study

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[770] Neela Banerjee, "Colorado Fracking Study Blames Faulty Wells for Water Contamination," *Inside Climate News*, July 11, 2016, https://insideclimatenews.org/news/11072016/water-contamination-near-colorado-fracking-tied-well-failures.

[771] U.S. Agency for Toxic Substances and Disease Registry, "Health Consultation: Dimock Groundwater Site" (U.S. Department of Health and Human Services, May 24, 2016), https://www.atsdr.cdc.gov/hac/pha/DimockGroundwaterSite/Dimock_Groundwater_Site_HC_05-24-2016_508.pdf.

[772] Abraham Lustgarten, "Federal Report Appears to Undercut EPA Assurances on Water Safety In Pennsylvania," *ProPublica*, June 9, 2016, https://www.propublica.org/article/federal-report-appears-to-undercut-epa-assurances-water-safety-pennsylvania.

[773] U.S. Environmental Protection Agency, "EPA Completes Drinking Water Sampling in Dimock, Pa.," press release (EPA, July 25, 2012), https://archive.epa.gov/epapages/newsroom_archive/newsreleases/1a6e49d193e1007585257a46005b61ad.html.

[774] Denise M. Akob et al., "Wastewater Disposal from Unconventional Oil and Gas Development Degrades Stream Quality at a West Virginia Injection Facility," *Environmental Science & Technology* 50, no. 11 (June 7, 2016): 5517–25, https://doi.org/10.1021/acs.est.6b00428.

[775] Darryl Fears, "This Mystery Was Solved: Scientists Say Chemicals From Fracking Wastewater Can Taint Fresh Water Nearby," *The Washington Post*, May 11, 2016, sec. Climate and Environment, https://www.washingtonpost.com/news/energy-environment/wp/2016/05/11/this-mystery-was-solved-scientists-say-chemicals-from-fracking-wastewater-can-taint-fresh-water-nearby/?utm_term=.c27045b60338.

was done in collaboration with Susan Nagel's team, which studied endocrine-disrupting activity in this same stream. See entry below for April 6, 2016.)

- April 30, 2016 – As part of an investigation based on aerial photographs taken by emergency responders during spring 2016 flooding, the *El Paso Times* documented plumes and sheens of chemicals from tipped-over storage tanks and inundated oil wells and fracking sites entering rivers and streams. "Many of the photos shot during Texas' recent floods show swamped wastewater ponds at fracking sites, presumably allowing wastewater to escape into the environment—and potentially into drinking-water supplies."[776]

- April 27, 2016 – Using geochemical and isotopic tracers to identify the unique chemical fingerprint of Bakken region brines, a Duke University study found that accidental spills of fracking wastewater have contaminated surface water and soils throughout North Dakota where more than 9,700 wells have been drilled in the past decade. Contaminants included salts as well as lead, selenium, and vanadium. In the polluted streams, levels of contaminants often exceeded federal drinking water guidelines. Soils at spill sites showed elevated levels of radium.[777] The study concluded that "inorganic contamination associated with brine spills in North Dakota is remarkably persistent, with elevated levels of contaminants observed in spill sites up to 4 years following the spill events." In a comment about this study, lead author and Duke University geochemist Avner Vengosh said, "Until now, research in many regions of the nation has shown that contamination from fracking has been fairly sporadic and inconsistent. In North Dakota, however, we find it is widespread and persistent, with clear evidence of direct water contamination from fracking."[778]

- April 6, 2016 – A research team led by Susan Nagel at the University of Missouri traced a spike in endocrine-disrupting activity in a West Virginia stream, Wolf Creek, to an upstream facility that stores fracking wastewater. Levels detected downstream of the waste facility were above levels known to create adverse health effects and alter the development of fish, amphibians, and other aquatic organisms. Endocrine-disrupting compounds were not elevated in upstream sections of the creek.[779, 780] (See also entry for May 9, 2016 above.)

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[776] Marty Schladen, "Flooding Sweeps Oil, Chemicals Into Rivers," *El Paso Times*, April 30, 2016, sec. News, http://www.elpasotimes.com/story/news/2016/04/30/flooding-sweeps-oil-chemicals-into-rivers/83671348/.
[777] Nancy E. Lauer, Jennifer S. Harkness, and Avner Vengosh, "Brine Spills Associated with Unconventional Oil Development in North Dakota," *Environmental Science & Technology* 50, no. 10 (2016): 5389–97, https://doi.org/10.1021/acs.est.5b06349.
[778] Nicholas School of the Environment, "Contamination in North Dakota Linked to Fracking Spills," press release (Duke University, April 27, 2016).
[779] Christopher D. Kassotis et al., "Endocrine Disrupting Activities of Surface Water Associated With a West Virginia Oil and Gas Industry Wastewater Disposal Site," *Science of the Total Environment* 557–558 (2016): 901–10, https://doi.org/10.1016/j.sci.tenv.2016.03.113.
[780] Brian Bienkowski, "In West Virginia, Frack Wastewater May Be Messing with Hormones," *Environmental Health News*, April 5, 2016, https://www.organicconsumers.org/news/west-virginia-frack-wastewater-may-be-messing-hormones.

- March 29, 2016 – A study by Stanford University scientists determined that fracking and related oil and gas operations have indeed contaminated drinking water in the town of Pavillion, Wyoming where residents have long complained about foul-tasting water. The researchers found substances in the water that match those used in local fracking operations or found in nearby pits used for the disposal of drilling waste. Chemical contaminants included benzene, a known carcinogen, and toluene, a neurotoxicant. Possible mechanisms for contamination include defective cement well casings; spills and leaks from disposal pits; and underground migration of chemicals into aquifers from the fracked zone, which, in this area, is quite shallow. Also, in the Pavillion area, operators sometimes fracked directly into underground sources of water.[781] One of the authors of this study, Dominic DiGuilio, was also a lead scientist on the EPA's earlier aborted investigation of Pavillion's drinking water. (See entry for December 6, 2015 below.) In an interview about his new research, DiGiulio said that his findings raise concerns about similar water pollution in other heavily fracked regions. "Pavillion isn't geologically unique in the West, and I'm concerned about the Rocky Mountain region of the U.S. The impact on [underground drinking water sources] could be fairly extensive. Pavillion is like a canary in a coal mine and we need to look at other fields."[782] Co-author Rob Jackson noted, "There are no rules that would stop a company from doing this anywhere else."[783]

- February 22, 2016 – Relying on voluntary disclosures reported to the FracFocus registry and a list compiled by the U.S. Congress, a German team surveyed the physiochemical properties of chemicals used in hydraulic fracturing fluid to evaluate their environmental fate and potential toxicity. Common ingredients included those known to contaminant groundwater, such as solvents, as well as those known to react strongly with other chemicals, such as biocides and strong oxidants, indicating that almost certainly, new chemical products are formed during the process of fracking and its aftermath. Hence, non-toxic additives could potentially react with other substances to create harmful byproducts. The authors conclude that a comprehensive assessment of risks would require an unabridged list of the chemical additives used for fracking, and they call for full disclosure.[784, 785]

- February 9, 2016 – An investigation of water contamination in the Barnett Shale by ABC-affiliate station WFAA in Dallas found numerous violations by operators who

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[781] Dominic C. DiGiulio and Robert B. Jackson, "Impact to Underground Sources of Drinking Water and Domestic Wells from Production Well Stimulation and Completion Practices in the Pavillion, Wyoming, Field," *Environmental Science & Technology* 50 (2016): 4524–36, https://doi.org/10.1021/acs.est.5b04970.
[782] Neela Banerjee, "Fracking Study Finds Toxins in Wyoming Town's Groundwater and Raises Broader Concerns," *Inside Climate News*, March 29, 2016, sec. Fossil Fuels, https://insideclimatenews.org/news/29032016/fracking-study-pavillion-wyoming-drinking-water-contamination-epa.
[783] Rob Jordan, "Stanford Researchers Show Fracking's Impact to Drinking Water Sources," *Stanford News*, March 29, 2016, http://news.stanford.edu/2016/03/29/pavillion-fracking-water-032916/.
[784] Martin Elsner and Kathrin Hoelzer, "Quantitative Survey and Structural Classification of Hydraulic Fracturing Chemicals Reported in Unconventional Gas Production," *Environmental Science & Technology* 50, no. 7 (2016): 3290–3314, https://doi.org/10.1021/acs.est.5b02818.
[785] American Chemical Society, "How to Get a Handle on Potential Risks Posed by Fracking Fluids," Phys.org, March 9, 2016, https://web.archive.org/web/20160310104849/http://phys.org/news/2016-03-potential-posed-fracking-fluids.html.

ignored regulations that require sealing vertical well pipes with a cement sheath to protect groundwater from stray gas and other vapors that might escape and migrate upwards into overlying aquifers. The WFAA report said that the Texas Railroad Commission, which oversees drilling and fracking operations in Texas, has failed to respond to alleged violations of a rule that requires cement seals around steel well casings in geological zones where drilling has penetrated layers of rock containing oil and gas deposits.[786]

- February 8, 2016 – An investigation by the *Columbus Dispatch* revealed that the amount of water that operators use for hydraulic fracturing in Ohio gas wells increased steadily from 2011 to 2015. The total amount of water increased, as did the volume of water used per well—from an average of 5.6 million gallons per well in 2011 to 7.6 million in 2014. The reason is that the horizontally drilled holes beneath each well have become longer, and these require more water during the fracking process.[787]

- February 2016 – In a lengthy account to Congress on the status of the underground waste injection well program that is overseen by the EPA, the U.S. Government Accountability Office (GAO) reported that the agency "has not consistently conducted oversight activities necessary to assess whether state and EPA-managed programs are protecting underground sources of drinking water" from contamination by fracking waste. Specifically, the GAO took the EPA to task for failure to require well-specific inspections, collect data on enforcement actions, review permitting requirements by state regulatory agencies, or analyze the resources the agency would need to do all the above to adequately oversee the Underground Injection Control program. The GAO noted that it had once before, in 2014, previously found the EPA negligent in its responsibilities to monitor drinking water sources for possible contamination with fracking waste.[788] (See entry below for September 23, 2014.)

- January 6, 2016 – Yale School of Public Health researchers analyzed more than 1,021 chemicals either used in fracking fluid or created during the process of hydraulic fracturing. They found that 781 of these chemicals lacked basic toxicity data. Of the 240 that remained, 157 were reproductive or developmental toxicants. These included arsenic, benzene, cadmium, formaldehyde, lead, and mercury.[789] Commenting on this study, lead author Nicole Deziel said, "This evaluation is a first step to prioritize the vast array of potential environmental contaminants from hydraulic fracturing for future exposure and health studies. Quantification of the potential exposure to these chemicals, such as by

[786] Brett Shipp, "Drilling Records Suggest Lax State Enforcement," *WFAA*, February 9, 2016, https://web.archive.org/web/20160914000244/http://www.wfaa.com/mb/news/local/investigates/rules-ignored-water-fouled-in-barnett-shale/38337835.
[787] Laura Arenschield, "Drillers Using More Water to Frack Ohio Shale," *The Columbus Dispatch*, February 8, 2016, http://www.dispatch.com/content/stories/local/2016/02/07/drillers-using-more-water-to-frack-ohio-shale.html.
[788] U.S. Government Accountability Office, "Drinking Water: EPA Needs to Collect Information and Consistently Conduct Activities to Protect Underground Sources of Drinking Water," February 2016, http://gao.gov/assets/680/675439.pdf.
[789] Elise G. Elliott et al., "A Systematic Evaluation of Chemicals in Hydraulic-Fracturing Fluids and Wastewater for Reproductive and Developmental Toxicity," *Journal of Exposure Science & Environmental Epidemiology* 27, no. 1 (2016): 90–99, https://doi.org/10.1038/jes.2015.81.

monitoring drinking water in people's homes, is vital for understanding the public health impact of hydraulic fracturing."[790]

- December 15, 2015 – A research team led by geologist Mukul Sharma from Dartmouth College discovered that chemical reactions between fracking fluid and rock can contribute to the toxicity of fracking wastewater. Specifically, the researchers found that fracking fluid can chemically react with the fractured shale in ways that cause barium, a toxic metal, to leach from clay minerals in the Marcellus Shale.[791, 792]

- December 6, 2015 – The *Caspar Star Tribune* investigated the EPA's decision to transfer its study of possible fracking-related drinking water contamination in Pavillion, Wyoming to a state agency in 2013. Preliminary data from the EPA suggested that drilling and fracking operations had contaminated drinking water supplies. To date, the state study has found no definitive link between drilling and water contamination. Interviews with officials and documents obtained under the Freedom of Information Act revealed that the EPA had bowed to political pressure from state officials and industry representatives and that Wyoming regulators narrowed the scope of the study considerably and conducted little fieldwork.[793] (See also entry above for March 29, 2016.)

- November 19, 2015 – The Science Advisory Board (SAB) for the EPA reviewed the EPA's June 2015 draft assessment of fracking's impacts on drinking water, and challenged some of the summary statements that accompanied it, saying that they were over-generalized and not always aligned with the data in the report itself. Specifically, the SAB said, in a draft review, that the data cited by the report were too limited to support the headlined claim in the executive summary that drinking water impacts were neither "widespread" nor "systemic." The SAB also critiqued the study for downplaying local impacts in its conclusions, noting that these impacts can sometimes be severe.[794]

- October 19, 2015 – A six-month investigation by *Penn Live* found long-standing "systemic failures" on the part of the Pennsylvania Department of Environmental Protection (PA DEP) to enforce regulations governing drilling and fracking operations. Lack of oversight and reliance on industry self-policing have been the hallmarks of Marcellus Shale development for the past ten years, in violation of Pennsylvanians'

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[790] Michael Greenwood, "Chemicals in Fracking Fluid and Wastewater Are Toxic, Study Shows," *Yale News*, January 6, 2016, http://news.yale.edu/2016/01/06/toxins-found-fracking-fluids-and-wastewater-study-shows.s

[791] Devon Renock, Joshua D. Landis, and Mukul Sharma, "Reductive Weathering of Black Shale and Release of Barium During Hydraulic Fracturing," *Applied Geochemistry* 65 (2016): 73–86, https://doi.org/10.1016/j.apgeochem.2015.11.001.

[792] Dartmouth College, "Fracking Plays Active Role in Generating Toxic Metal Wastewater, Study Finds," *Science Daily*, December 15, 2015, https://www.sciencedaily.com/releases/2015/12/151215134653.htm.

[793] Benjamin Storrow, "Pavillion Today: An EPA in Retreat, a Narrow State Inquiry and No Answers," *Casper Star Tribune*, December 6, 2015, http://trib.com/business/energy/pavillion-today-an-epa-in-retreat-a-narrow-state-inquiry/article_403f84de-830c-5558-9f3f-ea48fd48d7ca.html?utm_medium=social&utm_source=facebook&utm_campaign=user-share.

[794] Neela Banerjee, "EPA Finding on Fracking's Water Pollution Disputed by Its Own Scientists," *Inside Climate News*, November 19, 2015, https://insideclimatenews.org/news/19112015/fracking-water-pollution-epa-study-natural-gas-drilling.

constitutional right to clean air and water. Among the findings of this investigation: chronically leaking wastewater impoundments for which no fines or notices were issued to the operator; laboratory coding systems designed to obscure possible detections of certain chemical contaminants in residents' drinking water; and lack of inspections at well sites.[795]

- October 13, 2015 – An international team of researchers found detectable levels of multiple organic chemical contaminants in private drinking water wells in northeastern Pennsylvania where fracking is practiced. One of the compounds was a known additive of fracking fluid. Chemical fingerprinting and noble gas isotopes were used to determine if the contaminants most likely originated from surface spills at the well site or via upward transport from the shale itself. The organic pollutants found in the water did not contain chemical markers—certain elements and salts—that would indicate migration from deep geological strata. The authors concluded that "the data support a transport mechanism…to groundwater via accidental release of fracturing fluid chemicals derived from the surface rather than subsurface flow of these fluids from the underlying shale formation."[796, 797]

- September 23, 2015 – A team of researchers, examining how natural gas drilling and fracking operations across the nation affect creeks, streams and rivers, developed a predictive model and vulnerability index for surface water. They found that "all shale plays, regardless of location, had a suite of catchments that spanned highly degraded to those that are less altered and naturally sensitive to alteration." Surface water in Pennsylvania's Marcellus Shale region is classified by this model as vulnerable to fracking-related impacts because of steep slopes and loose, erodible soils within the watersheds.[798]

- July 30, 2015 – As reported by the *Los Angeles Times*, unlined waste pits and hillside spraying of oil-field wastewater have contaminated groundwater in Kern County, California. Five of six monitoring wells in the 94-acre waste site showed high levels of salt, boron, and chloride, but it is not known how far and fast the contaminated plume has traveled.[799]

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[795] Candy Woodall, "Pa. Regulators Fail to Protect Environment During Marcellus Shale Boom," *Penn Live*, October 19, 2015, http://www.pennlive.com/midstate/index.ssf/2015/10/state_regulators_fail_to_prote.html.
[796] Brian D. Drollette et al., "Elevated Levels of Diesel Range Organic Compounds in Groundwater Near Marcellus Gas Operations ARe Derived From Surface Activities," *Proceedings of the National Academy of Sciences* 112, no. 43 (2015): 13184–89, https://doi.org/10.1073/pnas.1511474112.
[797] Brian D. Drollette and Desiree L. Plata, "Hydraulic Fracturing Components in Marcellus Groundwater Likely From Surface Operations, Not Wells," *Phys.Org*, October 13, 2015, http://phys.org/news/2015-10-hydraulic-fracturing-components-marcellus-groundwater.html.
[798] Sally A. Entrekin et al., "Stream Vulnerability to Widespread and Emergent Stressors: A Focus on Unconventional Oil and Gas," *PLoS ONE* 10, no. 9 (2015): e0137416, https://doi.org/10.1371/journal.pone.0137416.
Julie Cart, "Central Valley Board Allows Wastewater Disposal to Continue Despite Contamination," *Los Angeles Times*, July 30, 2015, http://www.latimes.com/local/california/la-me-oil-waste-pits-20150731-story.html.

- July 21, 2015 – By surveying records for 44,000 wells fracked between 2010 and 2013, researchers from Stanford University, Duke University, and Ohio State University attempted a first-ever assessment of the range of depths at which fracking occurs across the United States. They found that many wells are shallower than widely presumed.[800] As the authors noted, vertical fractures are able to propagate 2,000 feet upward, and hence, "shallow hydraulic fracturing often has greater potential risks of contamination than deeper hydraulic fracturing does." This study showed that drinking water sources may be more vulnerable from upward migration of fracking contaminants than previously presumed. Surprisingly, the researchers found no strong relationship between depth and the volume of water and chemicals used for fracking. Many wells were both shallow and water-intensive, with significant variation in water use from state to state.[801]

- July 9, 2015 – A multi-volume report from the California Council of Science and Technology (CCST) found threats to groundwater in California from several parts of the fracking lifecycle, most notably from toxic wastewater. First, wastewater from California fracking operations is sometimes used for crop irrigation, in which case contaminants may seep from the surface of agricultural areas into groundwater. Second, nearly 60 percent of fracking wastewater in California is disposed of in unlined, open-air pits, a practice that is banned in almost all other states. There are 900 such waste disposal pits in the state, most of which are located in Kern County. Third, for many years, fracking wastewater in California has been mistakenly sent, via injection wells, directly into protected aquifers containing clean freshwater.[802] California's Division of Oil, Gas and Geothermal Resources allowed fracking wastes to be injected into aquifers that it believed were exempt from the U.S. Safe Drinking Water Act. Conceding this mistake, the agency has shut down 23 injection wells for fracking waste disposal and established a two-year timetable for phasing out other wells injecting waste into aquifers that should have been protected.[803] Fracking also threatens California's groundwater resources through water consumption, according to the CCST study. While this volume of water represents a small percentage of overall annual water consumption in California, fracking-related water use is, the study noted, disproportionately concentrated in areas of the state already suffering from water shortages. Further drawdowns of these aquifers may interfere with agricultural and municipal water needs.[804] In addition, because the oil-containing rock layers in California are located closer to the surface than in other states, the state's groundwater is potentially vulnerable to chemical contamination through vertical faults and fissures and via old and abandoned wells. The absence of evidence for

[800] Rob Jordan, "Shallow Fracking Raises Questions for Water, New Stanford Research Shows," *Stanford News*, July 21, 2015, http://news.stanford.edu/news/2015/july/fracking_water-jackson-072115.html.
[801] Robert A. Jackson et al., "The Depths of Hydraulic Fracturing and Accompanying Water Use Across the United States," *Environmental Science & Technology* 49, no. 5 (2015): 8969–76, https://doi.org/10.1021/acs.est.5b01228.
[802] Seth B. C. Shonkoff et al., "Chapter 6: Potential Impacts of Well Stimulation on Human Health in California," in *An Independent Scientific Assessment of Well Stimulation in California* (California Council on Science and Technology, 2015), 372–445, https://ccst.us/wp-content/uploads/160708-sb4-vol-II-6-1.pdf.
[803] David R. Baker, "U.S. Likely to Bar Oil-Waste Dumping Into 10 California Aquifers," *San Francisco Chronicle*, July 16, 2015, sec. Biz & Tech, http://www.sfchronicle.com/business/article/U-S-likely-to-bar-oil-waste-dumping-into-10-6389677.php.
[804] William T. Stringfellow et al., "Chapter 2: Impacts of Well Stimulation on Water Resources," in *An Independent Scientific Assessment of Well Stimulation in California* (California Council on Science & Technology, 2015), 49–181, http://ccst.us/publications/2015/vol-II-chapter-2.pdf.

direct contamination of groundwater by fracking, the study concluded, reflects absence of investigation rather than evidence of safety.[805]

- June 30, 2015 – The USGS released the first nationwide map of water usage for hydraulic fracturing. It shows wide geographic and temporal variation in the amount of water used to frack a single well. In general, gas wells consume more water per well (5.1 million gallons on average) than oil wells (4 million gallons). Median annual water volumes needed to frack a single horizontal oil or gas well increased dramatically—by a factor of 25 or more—between 2000 and 2014. A typical gas or oil well that is horizontally fracked now requires between six and eight Olympic-sized swimming pools of water. In 2014, the majority (58 percent) of new hydraulically fracked oil and gas wells were horizontally drilled. The watersheds where the most water was consumed for hydraulic fracturing are mostly located in southern or southwestern states and correspond to the following shale formations: the Eagle Ford and Barnett Shales in Texas; the Haynesville-Bossier Shale in Texas and Louisiana; the Fayetteville Shale in Arkansas; the Tuscaloosa Shale in Louisiana and Mississippi; and the Woodford Shale in Oklahoma. The Marcellus and Utica Shales—which underlie watersheds in parts of Ohio, Pennsylvania, West Virginia, and New York—were also in the top seven water-consuming shale plays in the United States.[806]

- June 26, 2015 – A decade-long USGS study of 11,000 public drinking water wells in California—nearly all the groundwater used for public supply—found high levels of potentially toxic contaminants in about 20 percent of the wells, affecting about 18 percent of the state's population.[807] Although the study did not specifically investigate contaminants from oil and gas extraction, it does provide evidence for farm irrigation draining into groundwater, raising questions about the possible contamination of drinking water aquifers from the reuse of fracking wastewater for crop irrigation.[808]

- June 16, 2015 – A University of Texas research team documented widespread drinking water contamination throughout the heavily drilled Barnett Shale region in northern Texas. The study, which analyzed 550 water samples from public and private water wells, found elevated levels of 19 different hydrocarbon compounds associated with fracking (including the carcinogen benzene and the reproductive toxicant, toluene), detections of methanol and ethanol, and strikingly high levels of 10 different metals.[809]

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[805] Jane C. S. Long, Jens T. Birkholzer, and Laura C. Feinstein, "An Independent Scientific Assessment of Well Stimulation in California: An Examination of Hydraulic Fracturing and Acid Stimulations in the Oil and Gas Industry," Summary Report (California Council on Science & Technology, July 9, 2015), http://ccst.us/publications/2015/2015SB4summary.pdf.

[806] Tanya J. Gallegos et al., "Hydraulic Fracturing Water Use Variability in the United States and Potential Environmental Implications," *Water Resources Research* 51, no. 7 (2015): 5839–45, https://doi.org/10.1002/2015WR017278.

[807] Kenneth Belitz, Miranda S. Fram, and Tyler D. Johnson, "Metrics for Assessing the Quality of Groundwater Used for Public Supply, CA, USA: Equivalent-Population and Area," *Environmental Science & Technology* 49, no. 14 (2015): 8330–38, https://doi.org/10.1021/acs.est.5b00265.

[808] Ellen Knickmeyer and Scott Smith, "Study Finds Contaminants in California Public-Water Supplies," *Phys.Org*, July 15, 2015, https://phys.org/news/2015-07-contaminants-california-public-water.html.

[809] Zacariah L. Hildenbrand et al., "A Comprehensive Analysis of Groundwater Quality in The Barnett Shale Region," *Environmental Science & Technology* 49, no. 13 (2015): 8254–62, https://doi.org/10.1021/acs.est.5b01526.

"In the abstract, we can't state that unconventional oil and gas techniques are responsible," the lead author, Zachariah Hildenbrand, said in a media interview. "But when you get into areas where drilling is happening, you find more instances of contamination. It's not coincidental. There are causes for concern."[810]

- June 5, 2015 – The EPA's long-awaited 600-page draft report on the potential impacts of fracking for drinking water resources confirmed specific instances of drinking water contamination linked to drilling and fracking activities. The report also identified potential mechanisms, both above and below ground, by which drinking water resources can be contaminated by fracking. In some cases, drinking water was contaminated by spills of fracking fluid and wastewater. In other cases, "[b]elow ground movement of fluids, including gas . . . have contaminated drinking water resources." The EPA investigators documented 457 fracking-related spills over six years but acknowledged that they do not know how many more may have occurred. Of the total known spills, 300 reached an environmental receptor such as surface water or groundwater. The EPA also conceded that insufficient baseline drinking water data and a lack of long-term systematic studies limited the power of its findings. The EPA investigation confirmed a number of specific instances where these potential mechanisms did indeed lead to drinking water contamination. An assertion in the EPA's accompanying press release that it had not found "widespread, systemic impacts to drinking water resources" was quoted out of context by many media sources as proof that fracking poses little threat to drinking water. To the contrary, this report confirmed that drilling and fracking activities have contaminated drinking water in some cases and acknowledged that it cannot ascertain how widespread the problem was due to insufficient data.[811] EPA Science Advisor Thomas A. Burke later clarified that the report does not show that fracking is safe. Burke said, "That is not the message of this report. The message of this report is that we have identified vulnerabilities in the water system that are really important to know about and address to keep risks as low as possible."[812]

- May 19, 2015 – A Pennsylvania State University research team documented the presence of a fracking-related solvent, 2-n-Butoxyethanol, in the drinking water from three homes in Bradford County, Pennsylvania, as part of an investigation of private drinking water wells near drilling and fracking operations that contained methane and foam. This finding represents the first fully documented case of a commonly used fracking chemical entering a drinking water source. "The most likely explanation of the incident is that stray natural gas and drilling or [hydrofracking] compounds were driven ~1-3 km along shallow to intermediate depth fractures to the aquifer used as a potable water source."[813] In an accompanying *New York Times* story, lead author Susan Brantley described the geology

[810] C. McPhate, "New Study Reveals Potential Contamination," *Denton Record-Chronicle*, June 18, 2015.
[811] U.S. EPA, "Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources," External review draft (U. S. Environmental Protection Agency, 2015), http://cfpub.epa.gov/ncea/hfstudy/recordisplay.cfm?deid=244651.
[812] Ken Ward Jr., "EPA Says New Study Doesn't Show Fracking Is Safe," *Charleston Gazette-Mail*, June 7, 2015, http://www.wvgazettemail.com/article/20150607/GZ01/150609432.
[813] Garth T. Llewellyn et al., "Evaluating a Groundwater Supply Contamination Incident Attributed to Marcellus Shale Gas Development," *Proceedings of the National Academy of Sciences* 112, no. 20 (2015): 6325–30, https://doi.org/10.1073/pnas.1420279112/-/DCSupplemental.

in northern Pennsylvania "as being similar to a layer cake with numerous layers that extend down thousands of feet to the Marcellus Shale. The vertical fractures are like knife cuts through the layers. They can extend deep underground, and can act like superhighways for escaped gas and liquids from drill wells to travel along, for distances greater than a mile away."[814]

- May 15, 2015 – A research team from the University of Colorado Boulder and California State Polytechnic Institute developed a model for identifying which fracking fluid chemicals are most likely to contaminate drinking water. Of 996 fracking fluid compounds known to be in use, researchers screened 659 of them for their ability to persist, migrate, and reach groundwater aquifers over a short time scale. Of the fifteen compounds so identified, two were commonly used in fracking operations: naphthalene and 2-butoxyethanol. Both are ingredients in surfactants and corrosion inhibitors. The authors noted that 2-butoxyethanol has been detected in drinking water in a heavily fracked area of Pennsylvania. Exposure to 2-butoxyethanol has been linked to birth defects in animals. Naphthalene is a possible human carcinogen that is toxic to red blood cells and contributes to kidney and liver damage. Researchers did not consider the impact of mixtures, interactions between contaminants, or chemical transformations during the fracking or flowback process and noted, "the need for data on the degradation of many compounds used in fracturing fluids under conditions relevant for groundwater transport."[815]

- May 7, 2015 – A survey of streams in Arkansas, led by the University of Central Arkansas, found alterations in macroinvertebrate communities to be related to drilling and fracking operations in the Fayetteville Shale. Fracking activity near streams was associated with greater sediment and more chlorophyll. "This study suggests that land disturbance from gas development affected stream communities."[816]

- April 20, 2015 – A USGS team analyzed water brought to the surface during natural gas extraction at 13 fracked wells in northern Pennsylvania. They found large variability in the VOCs and microorganisms in the water samples from different wells. Organic chemical contaminants included benzene, toluene, and perchloroethylene, chloroform, and methylene chloride. The presence of microbes was associated with concentrations of benzene and acetate. Despite the addition of biocides during the fracking process, hydrogen sulfide-producing bacteria were present at culturable levels, along with methogenic and fermenting bacteria. The source of these microorganisms was not determined. "Therefore, we cannot exclude the possibility that these microorganisms are native to the shale formation and reactivated by [hydrofracking] activities, as their

[814] Nicholas St. Fleur, "Fracking Chemicals Detected in Pennsylvania Drinking Water," *The New York Times*, May 4, 2015, sec. Climate and Environment, http://www.nytimes.com/2015/05/05/science/earth/fracking-chemicals-detected-in-pennsylvania-drinking-water.html?_r=0#addendums.
[815] Jessica D. Rogers et al., "A Framework for Identifying Organic Compounds of Concern in Hydraulic Fracturing Fluids Based on Their Mobility and Persistence in Groundwater," *Environmental Science & Technology Letters* 2, no. 6 (2015): 158–64, https://doi.org/10.1021/acs.estlett.5b00090.
[816] Erica Johnson et al., "Stream Macroinvertebrate Communities Across a Gradient of Natural Gas Development in the Fayetteville Shale," *Science of the Total Environment* 530–531 (2015): 323–32, https://doi.org/10.1016/j.scitotenv.2015.05.027.

physiology does not indicate a terrestrial surficial source."[817]

- April 8, 2015 – A University of Colorado Boulder research team's analysis of the organic chemicals found in liquid waste that flowed out of gas wells in Colorado after they had been fracked revealed the presence of many fracking fluid additives, including biocides, which are potentially harmful if they leak into groundwater. According to the authors, treatment of fracking wastewater must include aeration, precipitation, disinfection, a biological treatment to remove dissolved organic matter, and reverse osmosis desalination in order for it to be appropriate for non-fracking uses, such as crop irrigation.[818]

- March 18, 2015 – Using a new stream-based monitoring method, a team of scientists with USGS, Pennsylvania State University, and University of Utah found elevated levels of methane in groundwater discharging into a stream near drilling and fracking operations in Pennsylvania. In this same area, several private water wells contained high levels of methane as a result of gas migration near a gas well with a defective casing. The monitoring technique used by the scientists allowed them to demonstrate that the source of the methane was shale gas from the Middle Devonian period, which is the kind of gas found in the Marcellus Shale.[819] Researcher Susan Brantley said, "I found it compelling that using this new method for a reconnaissance of just 15 streams in Pennsylvania, we discovered one instance of natural gas entering the stream, perhaps from a nearby leaking shale gas well."[820]

- March 12, 2015 – A team led by geologist Donald Siegel of Syracuse University found no relationship between methane levels in drinking water wells and proximity to oil or gas wells in a heavily fracked area of northeastern Pennsylvania.[821] However, Siegel failed to reveal in his paper — as is required by the journal — that he had received industry funding from the Chesapeake Energy Corporation. Subsequently, the journal published a lengthy correction that revealed that Chesapeake had not only privately funded the lead author but had provided the baseline groundwater data set. A second author was revealed to be a former employee of Chesapeake, and another had worked as

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[817] Denise M. Akob et al., "Organic and Inorganic Composition and Microbiology of Produced Waters From Pennsylvania Shale Gas Wells," *Applied Geochemistry* 60 (2015): 116–25, https://doi.org/10.1016/j.apgeochem.2015.04.011.
[818] Yaal Lester et al., "Characterization of Hydraulic Fracturing Flowback Water in Colorado: Implications for Water Treatment," *Science of the Total Environment* 512–513 (2015): 637–44, https://doi.org/10.1016/j.scitotenv.2015.01.043.
[819] Victor M. Heilweil et al., "Stream Measurements Locate Thermogenic Methane Fluxes in Groundwater Discharge in an Area of Shale-Gas Development," *Environmental Science & Technology* 49, no. 7 (2015): 4057–65, https://doi.org/10.1021/es503882b.
[820] U.S. Geological Survey, "Exploring: New Stream Monitoring Method Locates Elevated Groundwater Methane In Shale-Gas Development Area," *Science Explorer*, April 1, 2015, https://www.usgs.gov/science-explorer-results?es=New+stream+monitoring+method+locates+elevated+groundwater+methane+in+shale-gas+development+area.
[821] Donald L. Siegel et al., "Methane Concentrations in Water Wells Unrelated to Proximity to Existing Oil and Gas Wells in Northeastern Pennsylvania," *Environmental Science & Technology* 49, no. 7 (2015): 4106–12, https://doi.org/10.1021/es505775c.

a consultant in the energy sector.[822]

- March 3, 2015 – A Duquesne University study of private drinking water wells in an intensely drilled southwestern Pennsylvania community compared pre-drill and post-drill data on water quality and found changes in water chemistry that coincided with the advent of drilling and fracking activities. Levels of chloride, iron, barium, strontium, and manganese were elevated. In some cases, concentrations exceeded health-based maximum contaminant levels. Methane was detected in most houses tested. Surveys of residents revealed widespread complaints about changes in water quality that began after drilling and fracking operations commenced. Violation records from the PA DEP uncovered possible pathways for water contamination. The researchers concluded that alterations of local hydrology caused by the injection of large volumes of hydraulic fracturing fluids may have mobilized contaminants left over from legacy oil, gas, and mining operations as well as opened pathways for the migration of fracking fluids themselves.[823]

- March 3, 2015 – A research team from Duquesne University reviewed the evidence for environmental impacts to air and water from activities related to shale gas extraction in Pennsylvania and explored potential mechanisms for contamination of air and water related to the drilling and fracking process itself. Among them: deformations of the shale bedrock caused by the injection of large volumes of fluid result in "pressure bulbs" that are translated through rock layers and can impact faults and fissures, so affecting groundwater.[824]

- February 23, 2015 – The arrival of drilling and fracking activities coincided with an increase in salinity in a creek that drains public land in a semi-arid region of Wyoming, determined a USGS study. The dissolved minerals associated with the rise in salinity matched those found in native soil salts, suggesting that disturbance of naturally salt-rich soils by ongoing oil and gas activities, including pipeline, road, and well pad construction, was the culprit. "As [shale gas and oil] development continues to expand in semiarid lands worldwide, the potential for soil disturbance to increase stream salinity should be considered, particularly where soils host substantial quantities of native salts."[825]

- February 14, 2015 – A review by a *Dickinson Press* news reporter of disposal well files

[822] Donald L. Siegel et al., "Correction to Methane Concentrations in Water Wells Unrelated to Proximity to Existing Oil and Gas Wells in Northeastern Pennsylvania," *Environmental Science & Technology* 49, no. 9 (2015): 5840, https://doi.org/10.1021/acs.est.5b01800.
[823] Shyama K. Alawattegama et al., "Well Water Contamination in a Rural Communityt in Southwestern Pennsylvania Near Unconventional Shale Gas Extraction," *Journal of Environmental Science and Health, Part A* 50, no. 5 (2015): 516–28, https://doi.org/10.1080/10934529.2015.992684.
[824] David J. Lampe and John F. Stolz, "Current Perspectives on Unconventional Shale Gas Extraction in the Appalachian Basin," *Journal of Environmental Science and Health, Part A* 50, no. 5 (2015): 464–446, https://doi.org/10.1080/10934529.2015.992653.
[825] Carleton R. Bern et al., "Soil Disturbance as a Driver of Increased Stream Salinity in a Semiarid Watershed Undergoing Energy Development," *Journal of Hydrology: Regional Studies* 524 (2015): 123–36, https://doi.org/10.1016/j.jhydrol.2015.02.020.

and more than 2,090 mechanical integrity tests revealed that North Dakota frack waste injection wells were often leaky and that state regulators continued to allow fluid injection into wells with documented structural problems even though the wells did not meet EPA guidelines for wellbore integrity. Officials with the North Dakota Division of Oil and Gas said they had primary enforcement responsibilities and that EPA guidance did not apply to these wells. The investigation noted, "… a review of state and federal documents, as well as interviews with geologists, engineers, environmental policy experts and lawyers who have litigated under the Safe Drinking Water Act, suggests the agency is loosely interpreting guidance and protocols that are meant to maintain the multiple layers of protection that separate aquifers from the toxic saltwater." *The Dickinson Press* is the daily newspaper for Stark County in southwest North Dakota.[826]

- February 11, 2015 – The *Los Angeles Times* analyzed self-reported testing results on fracking wastewater that California drillers were required to submit to the state. Samples of wastewater collected from 329 fracked oil wells found that virtually all—98 percent—contained benzene at levels that exceeded standards for permissible concentrations in drinking water. This finding likely underrepresents the extent of the problem, according to the newspaper investigation, because many operators failed to comply with reporting requirements. The discovery that fracking wastewater is high in benzene is particularly alarming in light of the admission by the state of California that it had inadvertently allowed frack waste disposal directly into aquifers containing clean water that could potentially be used for drinking. Those wells are now the subject of federal and state review.[827]

- February 1, 2015 – An investigation of the chemical make-up of fracking fluid found that the compositions of these mixtures vary widely according to region and company, making the process of identifying individual compounds difficult. Classes of hydrocarbon-based chemicals include solvents, gels, biocides, scale inhibitors, friction reducers, and surfactants. Chemical analysis identified around 25 percent of the organic compounds that are believed to be present in fracking fluid and that are necessary to test for in identifying groundwater and drinking water contamination.[828] Dr. Imma Ferrer, lead author, explained in a *Science Daily* article about her research that "[b]efore we can assess the environmental impact of the fluid, we have to know what to look for."[829]

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[826] A. Brown, "Lacking Integrity? State Regulatory Officials Don't Follow EPA Guidance on Saltwater Disposal Wells.," *The Dickinson Press*, February 14, 2015, https://www.thedickinsonpress.com/business/3679507-lacking-integrity-state-regulatory-officials-dont-follow-epa.
[827] J. Cart, "High Levels of Benzene Found in Fracking Waste Water," *Los Angeles Times*, February 11, 2015, http://www.latimes.com/local/california/la-me-fracking-20150211-story.html#page=1.
[828] Imma Ferrer and E. Michael Thurman, "Chemical Constituents and Analytical Approaches for Hydraulic Fracturing Waters," *Trends in Environmental Analytical Chemistry* 5 (2015): 18–25, https://doi.org/10.1016/j.teac.2015.01.003.
[829] Elsevier, "Fracking Fluids Contain Potentially Harmful Compounds If Leaked Into Groundwater," *Science Daily*, April 8, 2015, https://www.sciencedaily.com/releases/2015/04/150408090323.htm.

- January 30, 2015 – A USGS review of national water quality databases found that insufficient data exist to understand the impact of fracking on drinking water.[830] In a media interview, lead author Zack Bowen said, "There are not enough data available to be able to assess the potential effects of oil and gas development over larger geographic areas."[831]

- January 21, 2015 – A team of researchers from the USGS and Virginia Tech University established that petroleum-based hydrocarbons can break down underground in ways that promote the leaching of naturally occurring arsenic into groundwater. Arsenic is a known human carcinogen that causes bladder, lung, and skin cancer. Elevated levels of arsenic in drinking water represent a public health threat.[832] Researchers found that arsenic concentrations in a hydrocarbon plume can reach 23 times the current drinking water standard of 10 micrograms per liter. The authors of the study said that the metabolism of carbon-rich petroleum products by subterranean microbes is involved in a complex geochemical process that leads to mobilization of arsenic into aquifers.[833]

- January 14, 2015 – Researchers from Duke University, Dartmouth College, and Stanford University found high levels of iodide, bromide, and ammonium in samples of wastewater from fracking operations in both the Marcellus and Fayetteville Shales. These same chemicals were present when fracking wastewater was discharged into rivers and streams at three treatment sites in Pennsylvania and during an accidental spill in West Virginia. Iodide and bromide are known to create toxic disinfection byproducts when downstream water is subsequently chlorinated for drinking water. In water, ammonium can convert to ammonia, which is toxic to aquatic life. The authors noted that this is the first study to identify ammonium and iodide as widespread in fracking waste discharges.[834] In an interview with the *Pittsburgh Post-Gazette*, lead author Avner Vengosh said that the findings raise new concerns about the environmental and health impacts of wastewater from drilling and fracking operations.[835]

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[830] Zachary H. Bowen et al., "Assessment of Surface Water Chloride and Conductivity Trends in Areas of Unconventional Oil and Gas Development—Why Existing National Data Sets Cannot Tell Us What We Would Like to Know," *Water Resources Research* 51 (2015): 704–15, https://doi.org/10.1002/2014WR016382.
[831] Susan Phillips, "USGS: Fracking Water Quality Data 'Scarce,'" *State Impact Pennsylvania*, March 3, 2015, https://stateimpact.npr.org/pennsylvania/2015/03/03/usgs-fracking-water-quality-data-scarce/.
[832] U.S. Geological Survey, "Exploring: Natural Breakdown Of Petroleum Underground Can Lace Arsenic Into Groundwater," *Science Explorer*, January 26, 2015, https://www.usgs.gov/science-explorer-results?es=Natural+breakdown+of+petroleum+underground+can+lace+arsenic+into+groundwater.
[833] Isabelle M. Cozzarelli et al., "Arsenic Cycling in Hydrocarbon Plumes: Secondary Effects of Natural Attenuation," *Groundwater* 54, no. 1 (2016): 35–45, https://doi.org/10.1111/gwat.12316.
[834] Harkness, J. S., Dwyer, G. S., Warner, N. R., Parker, K. M., Mitch, W. A., & Vengosh, A. (2015). Iodide, bromide, and ammonium in hydraulic fracturing and oil and gas wastewaters: environmental implications. *Environmental Science & Technology*, *49,* 1955-63. doi: Jennifer S. Harkness et al., "Iodide, Bromide, and Ammonium in Hydraulic Fracturing and Oil and Gas Wastewaters: Environmental Implications," *Environmental Science & Technology* 49, no. 3 (2015): 1955–63, https://doi.org/10.1021/es504654n.
[835] Don Hopey, "Study: High Levels of Pollutants From Drilling Waste Found in Pa. Rivers," *Pittsburgh Post-Gazette*, January 14, 2015, http://powersource.post-gazette.com/powersource/latest-oil-and-gas/2015/01/14/Study-High-levels-of-pollutants-from-drilling-waste-found-in-Pennsylvania-rivers-shale/stories/201501140143.

- November 27, 2014 – An interdisciplinary team of researchers found methane contamination in drinking water wells located in eight areas above the Marcellus Shale in Pennsylvania and the Barnett Shale in Texas, with evidence of declining water quality in the Barnett Shale area. By analyzing noble gases and their isotopes (helium, neon, argon), the investigators were able to isolate the origin of the fugitive methane in drinking water. The results implicate leaks through cement well casings as well as via naturally occurring cracks and fissures in the surrounding rock.[836] In a related editorial, one of the study's authors, Robert Jackson, called on the EPA to reopen its aborted investigation into drinking water contamination in heavily fracked areas of Texas. Jackson also emphasized that methane migration through unseen cracks in the rock surrounding the wellbore "raises the interesting possibility that a drilling company could follow procedures — cementing and casing below the local aquifer — and still create a potential pathway for gas to migrate into drinking water."[837]

- November 26, 2014 – A critical review of biocides in fracking fluid by a Colorado State team found that the fate of these chemicals underground is not known and their toxicity not well understood. While many biocides are short-lived, some may transform into more toxic or persistent compounds. Among the most common chemical components of fracking fluid, biocides are used to inhibit the growth of deep-life microorganisms, including sulfate-reducing bacteria that contribute to corrosion of well casings and can form biofilms that prevent the upward flow of natural gas. Oxidizing biocides that are chlorine- or bromine-based can react with other fracking chemicals and may produce toxic halogenated byproducts. The authors noted biocides pose a unique risk for drinking water when fracking liquid waste is treated for discharge to surface water via sewage treatment plants. Sub-lethal concentrations may contribute to adaptation of surviving microorganisms and, hence, antibiotic resistance of pathogens. They cited particular concern over surface spills and well integrity issues associated with casing or cement failure.[838]

- November 3, 2014 – The West Virginia Department of Environmental Protection confirmed that three private drinking water wells were contaminated when Antero Resources mistakenly drilled into one of its own gas wells. Benzene, a human carcinogen, and toluene, a reproductive toxicant, were detected in the drinking water at concentrations four times the legal maximum limit. Additionally, a nearby abandoned gas well, a drinking water well, and an actively producing gas well were all pressurized as a result of the mishap and began exhibiting "artesian flow."[839]

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[836] Thomas H. Darrah et al., "Noble Gases Identifying the Mechanisms of Fugitive Gas Contamination in Drinking-Water Wells Overlying the Marcellus and Barnett Shales," *Proceedings of the National Academy of Sciences* 111, no. 39 (2014): 14076–81, https://doi.org/10.1073/pnas.1322107111.
[837] Rob Jackson, "Reopen Barnett Shale Water Probe," *The Texas Tribune*, December 1, 2014, http://tribtalk.org/2014/12/01/reopen-barnett-shale-water-probe/.
[838] Genevieve A. Kahrilas et al., "Biocides in Hydraulic Fracturing Fluids: A Critical Review of Their Usage, Mobility, Degradation, and Toxicity," *Environmental Science & Technology* 49, no. 1 (2015): 16–32, https://doi.org/10.1021/es503724k.
[839] Glynis Board, "DEP: September Drilling Accident Contaminated Water in Doddridge County," *West Virginia Public Broadcasting*, November 3, 2014, http://wvpublic.org/post/dep-september-drilling-accident-contaminated-water-doddridge-county.

- October 22, 2014 – A follow-up to the August 2014 Environmental Integrity Project report describes an even greater potential public health threat from a loophole in the Safe Drinking Water Act, wherein companies are allowed to inject other petroleum products (beyond diesel) without a permit, and many of these non-diesel drilling fluids contain even higher concentrations of the same toxins found in diesel. The authors recommend that "EPA should revisit its guidance and broaden the categories of diesel products that require Safe Drinking Water Act permits before they can be injected into oil and gas wells."[840]

- October 20, 2014 – While developing a technique to fingerprint and trace accidental releases of hydraulic fracturing fluids, researchers showed that liquid waste from shale gas fracking operations is chemically different than waste flowing out of conventional wells. The researchers hypothesized that the hydraulic fracturing process itself liberates elements from clay minerals in the shale formations, including boron and lithium, which then enter the liquid waste.[841]

- October 15, 2014 – Four thousand gallons of liquid fracking waste dumped into Waynesburg sewer system was discovered by sewage treatment plant workers in Greene County, Pennsylvania. The Department of Environmental Protection surmised that "someone removed a manhole cover in a remote location and dumped the fluid." The treatment plant discharges into a creek that feeds the Monongahela River, which provides drinking water to more than 800,000 people.[842]

- October 6, 2014 – A state investigation that found no fracking-related water contamination in a drinking water well in Pennsylvania's Washington County was invalidated by testimony presented to the state Environmental Hearing Board. Not all contaminants that were present in the water were reported, and the investigation relied on obsolete testing methods. More sophisticated testing revealed the presence of several chemical contaminants in the well water. The well is located 2,800 feet down gradient from a drilling site and fracking waste pit where multiple spills and leaks more than four years earlier had contaminated two springs.[843]

- September 23, 2014 – In a two-part audit of records, the GAO found that the EPA is failing to protect U.S. drinking water sources from fracking-related activities such as waste disposal via injection wells. Nationwide, 172,000 injection wells accept fracking

[840] Eric Schaeffer and Courtney Bernhardt, "Fracking's Toxic Loophole" (The Environmental Integrity Project, October 22, 2014).
[841] N. R. Warner et al., "New Tracers Identify Hydraulic Fracturing Fluids and Accidental Releases from Oil and Gas Operations," *Environmental Science & Technology* 48, no. 21 (2014): 12552–60, https://doi.org/10.1021/es5032135.
[842] Don Hopey, "Waynesburg Officials Investigate Dumping of Fracking Wastewater," *Pittsburgh Post-Gazette*, October 14, 2014, https://www.post-gazette.com/news/environment/2014/10/15/Waynesburg-investigates-dumping-of-fracking-wastewater/stories/201410150056.
[843] Don Hopey, "Testimony: Obsolete Tests Tainted Shale Analysis," *Pittsburgh Post-Gazette*, October 5, 2014, http://powersource.post-gazette.com/powersource/companies-powersource/2014/10/06/Testimony-Obsolete-tests-tainted-shale-analysis/stories/201410060075.

waste; some are known to have contaminated drinking water. And yet, both short-term and long-term monitoring is lax, and record-keeping varies widely from state to state. The EPA neither mandates nor recommends a fixed list of chemicals for monitoring on the grounds that "injection fluids can vary widely in composition and contain different naturally occurring chemicals and fluids used in oil and gas production depending on the source of the injection fluid."[844] Disposal of oil and gas waste via injection wells is, in fact, subject to regulation under the Safe Drinking Water Act, but, in practice, no one knows exactly what the waste contains, and regulations are deficient. In the United States, at least two billion gallons of fluids are injected into the ground *each day* to enable oil and gas extraction via fracking or to dispose of liquid waste from fracking operations.[845, 846]

- September 18, 2014 – Range Resources was fined a record $4.5 million by the Pennsylvania Department of Environmental Protection for contaminating groundwater. The culprits were six leaking pits in Washington County that each held millions of gallons of fracking wastewater.[847]

- September 12, 2014 – A Pennsylvania State ecosystems scientist, together with USGS scientists, reviewed the current knowledge of the effects of fracking and its associated operations on terrestrial and aquatic ecosystems in 20 shale plays in the U.S. Findings of species and habitats at highest risk include (in addition to land-based examples) vernal pond inhabitants and stream biota. The research builds on previous reviews identifying "three main potential stressors to surface waters: changes in water quantity (hydrology), sedimentation, and water quality." Researchers determined that there are no published data specifically on the effects of fracking on forest-dwelling amphibians, but "many species breed in vernal ponds which are negatively affected by changes in water quantity and quality and direct disturbance. Many amphibians are also highly sensitive to road salts." Given that the U.S. EPA recently found 55 percent of all rivers and streams to be in poor condition, these researchers warned, "Large-scale development of shale resources might increase these percentages." They expressed concern for the native range of brook trout by the cumulative effects of shale development, especially in Pennsylvania.[848]

- September 9, 2014 – A research team from Stanford and Duke Universities discovered that fracking wastewater processed by sewage treatment plants contributes to the

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[844] U.S. Government Accountability Office, "Drinking Water: Characterization of Injected Fluids Associated with Oil and Gas Production" (U.S. GAO, September 23, 2014), http://www.gao.gov/products/GAO-14-857R.
[845] Naveena Sadasivam, "Report Criticizes EPA Oversight of Injection Wells," *ProPublica*, July 29, 2014, https://www.propublica.org/article/report-criticizes-epa-oversight-of-injection-wells.
[846] U.S. Government Accountability Office, "Drinking Water: EPA Program to Protect Underground Sources from Injection of Fluids Associated with Oil and Gas Production Needs Improvement" (U.S. GAO, June 27, 2014), http://www.gao.gov/products/GAO-14-555.
[847] Don Hopey, "Range Resources to Pay $4.15M Penalty," *Pittsburgh Post-Gazette*, September 18, 2014, http://www.post-gazette.com/local/2014/09/18/DEP-orders-Range-Resources-to-pay-4-million-fine/stories/201409180293.
[848] Margaret C. Brittingham et al., "Ecological Risks of Shale Oil and Gas Development to Wildlife, Aquatic Resources and Their Habitats," *Environmental Science & Technology* 48, no. 19 (2014): 11034–47, https://doi.org/10.1021/es5020482.

formation of carcinogenic chemical byproducts. These raise public health risks when downstream surface water is used for drinking. Even when fracking wastewater was diluted by a factor of 10,000, the bromides and iodides in the waste reacted with organic matter to create highly toxic halogenated compounds—at troublingly high concentrations. These toxic compounds are not filterable by municipal wastewater treatment plants. Halogenated disinfection byproducts in drinking water are linked to both colon and bladder cancers.[849]

- August 29, 2014 – A review of Pennsylvania Department of Environmental Protection files on fracking-related damage to drinking water—which are kept on paper and stored in regional offices—revealed that 243 private water supplies in 22 counties had been contaminated or had lost flow and dried up as a result of nearby drilling and fracking operations in the past seven years. Pollutants included methane, metals, and salts as well as carbon-based compounds (ethylene glycol and 2-butoxyethanol) that are known to be constituents of fracking fluid. As reported by the *Pittsburgh Post-Gazette*, this tally—which came as a response to multiple lawsuits and open-records requests by media sources—was the first time the agency "explicitly linked a drilling operation to the presence of industrial chemicals in drinking water."[850, 851]

- August 13, 2014 – Over the last decade, drilling companies have repeatedly claimed they are no longer using diesel fuel in fracking, although a 2011 investigation by U.S. House Democrats concluded otherwise. The Environmental Integrity Project examined disclosure data submitted to FracFocus and identified at least 351 wells in 12 states that have been fracked over the last four years with one or more of the five prohibited products identified as diesel. EIP researchers also discovered numerous fracking fluids with high diesel content for sale online, including over a dozen products sold by Halliburton and advertised as additives, friction reducers, emulsifiers, etc.[852]

- August 13, 2014 – An international team of researchers found high levels of carbon-based compounds in liquid fracking waste. These impurities can react with chlorine and bromine to create toxic byproducts. This study suggests that chemical treatment of liquid

[849] Kimberly M. Parker et al., "Enhanced Formation of Disinfection Byproducts in Shale Gas Wastewater-Impacted Drinking Water Supplies," *Environmental Science & Technology* 48, no. 19 (2014): 11161–69, https://doi.org/10.1021/es5028184.
[850] Pennsylvania Department of Environmental Protection, "Water Supply Determination Letters," August 29, 2014, http://files.dep.state.pa.us/OilGas/BOGM/BOGMPortalFiles/OilGasReports/Determination_Letters/Regional_Determination_Letters.pdf.
[851] Laura Legere, "DEP Releases Updated Details on Water Contamination Near Drilling Sites," *Pittsburgh Post-Gazette*, September 9, 2014, http://powersource.post-gazette.com/powersource/policy-powersource/2014/09/09/DEP-releases-details-on-water-contamination/stories/201409090010.
[852] Mary Greene, "Fracking Beyond the Law: Despite Industry Denials, Investigation Reveals Continued Use of Diesel Fuels in Hydraulic Fracturing" (The Environmental Integrity Project, August 13, 2014), https://www.environmentalintegrity.org/wp-content/uploads/2016/11/2014-08_Fracking-Beyond-the-Law.pdf.

fracking waste will magnify its toxic potency, as will reusing and recycling it.[853] The European Commission subsequently published a summary of these findings.[854]

- August 13, 2014 – A team from Lawrence Berkeley National Laboratory reported that scientific efforts to understand the hazards of fracking continue to be hampered by industry secrecy. A comprehensive examination of the chemical formulations of fracking fluid—whose precise ingredients are protected as proprietary business information—revealed that no publicly available toxicity or physical chemical information was available for one-third of all the fracking chemicals surveyed. Another ten percent of chemicals, including biocides and corrosion inhibitors, were known to be toxic to mammals.[855, 856]

- August 12, 2014 – A Stanford University research team working in the Pavillion gas basin in Wyoming documented that fracking in shallow layers of bedrock, including those that serve as drinking water aquifers, is not uncommon. This finding overturns the industry claim that oil and gas deposits targeted by fracking operations are located at much greater depths than underground drinking water sources and are isolated from them by hundreds of feet of impermeable rock. Because it is exempt from provisions of the Safe Drinking Water Act, fracking in drinking water aquifers is not prohibited by law.[857]

- August 3, 2014 – An investigation by the *Pittsburgh Post-Gazette* found that half of all fracking-related spills that resulted in violations and fines were not discovered by the gas companies themselves, even though Pennsylvania state law requires them to pro-actively seek and report such incidents. The newspaper's analysis of hundreds of thousands of state and company documents showed that self-regulation in the gas fields is a failure. One-third of all spills were discovered by state inspectors, while one-sixth were found by residents. Likely, much contamination is entirely undetected and unreported.[858]

- July 21, 2014 – An investigation by the *Columbus Dispatch* showed that Halliburton delayed disclosure to federal and state EPA agencies of the full list of chemicals that spilled into a creek following a fire on one of its well pad in Monroe County, Ohio. Although the creek is an important supply of drinking water for downstream communities

[853] Samuel J. Maguire-Boyle and Andrew R. Barron, "Organic Compounds in Produced Waters From Shale Gas Wells," *Environmental Science: Processes & Impacts* 16, no. 10 (2014), https://doi.org/10.1039/C4EM00376D.
[854] European Commission, "Chemical Composition of Fracking Wastewater," *Science for Environment Policy*, no. 404 (February 19, 2015), http://ec.europa.eu/environment/integration/research/newsalert/pdf/chemical_composition_of_fracking_wastewater_404na4_en.pdf.
[855] W. T. Stringfellow, et al., "Characterizing Compounds Used in Hydraulic Fracturing: A Necessary Step for Understanding Environmental Impacts" (American Chemical Society, San Francisco, CA, August 13, 2014).
[856] Philip Robinson, "Fracking Fluid Survey Shows Missing Information," *Scientific American*, August 19, 2014, http://www.scientificamerican.com/article/fracking-fluid-survey-shows-missing-information/.
[857] Neela Banerjee, "Oil Companies Fracking Into Drinking Water Sources, New Research Finds.," *Los Angeles Times*, August 12, 2014, http://www.latimes.com/nation/la-na-fracking-groundwater-pavillion-20140811-story.html#page=1.
[858] Sean D. Hamill, "Drillers Did Not Report Half of Spills That Led to Fines," *Pittsburgh Post-Gazette*, August 2, 2014, http://www.post-gazette.com/news/state/2014/08/03/Drillers-did-not-report-half-of-spills-that-led-to-fines/stories/201408020142.

and the spill precipitated a mass die-off of fish and other aquatic wildlife, five full days passed before EPA officials were provided a full inventory of chemicals used at Halliburton's operation. As a result, the public was denied knowledge of potential chemical exposures.[859]

- July 17, 2014 – A team of environmental scientists, biologists, and engineers, from institutions including the University of Michigan and McGill University, assessed the current state of understanding of the impact fracking and its associated activities have on the ecological health of surface waters. Though various approaches such as geographic information systems and site monitoring provide insights into potential risks to aquatic ecosystems, the authors concluded that inadequate data currently exist. They identified possible outcomes such as, "erosion and sedimentation, increased risk to aquatic ecosystems from chemical spills or runoff, habitat fragmentation, loss of stream riparian zones, altered biogeochemical cycling, and reduction of available surface and hyporheic water volumes because of withdrawal-induced lowering of local groundwater levels."[860]

- July 7, 2014 – California Department of Gas, Oil, and Geothermal Resources ordered seven energy companies to stop injecting liquid fracking waste into aquifers. The ongoing drought that has compelled farmers to supplement irrigation with water drawn from groundwater sources prompted state officials to look at the status of aquifers previously considered too deep for use or too poor in quality. They discovered that at least seven injection wells were very likely pumping liquid fracking waste into protected groundwater supplies rather than aquifers that had been sacrificed for the purpose of waste disposal. Across the United States, more than 1000 aquifers are exempt from any type of pollution protection at all, and many of these are in California, according to a related *ProPublica* investigation.[861]

- June 25, 2014 – A study by Cornell University researchers found that fracking fluid and fracking wastewater mobilized previously deposited chemical contaminants in soil particles in ways that could potentially exacerbate the impacts of fracking fluid spills or leaks. The research team concluded that, by interfering with the ability of soil to bond to and sequester pollutants such as heavy metals, fracking fluids may release from soils an additional repository of contaminants that could migrate into groundwater.[862]

- June 23, 2014 – Building on earlier findings that water samples collected from sites with confirmed fracking spills in Garfield County, Colorado exhibited moderate to high levels of estrogen and androgen-disrupting activity, a University of Missouri team extended

[859] Laura Arenschield, "Halliburton Delayed Releasing Details on Fracking Chemicals After Monroe County Spill," *The Columbus Dispatch*, July 21, 2014, http://www.dispatch.com/content/stories/local/2014/07/21/details-on-chemicals-trickle-in-after-spill.html.
[860] G. Allen Burton Jr. et al., "Hydraulic 'Fracking': Are Surface Water Impacts an Ecological Concern?," *Environmental Toxicology and Chemistry* 33, no. 8 (2014): 1679–89, https://doi.org/10.1002/etc.2619.
[861] Abrahm Lustgarten, "California Halts Injection of Fracking Waste, Warning It May Be Contaminating Aquifers," *ProPublica*, July 18, 2014, http://www.propublica.org/article/ca-halts-injection-fracking-waste-warning-may-be-contaminating-aquifers.
[862] W. Sang et al., "Effect of Hydrofracking Fluid on Colloid Transport in the Unsaturated Zone," *Environmental Science & Technology* 48, no. 14 (2014): 8266–74, https://doi.org/10.1021/es501441e.

their investigation to other types of hormonal effects. As reported at a joint meeting of the International Society of Endocrinology and the Endocrine Society, their research documented that commonly used fracking chemicals can also block the receptors for thyroid hormone, progesterone, and glucocorticoids (a family of hormones involved in both fertility and immune functioning). Of 24 fracking chemicals tested, all 24 interfered with the activity of one or more important hormone receptors. There is no known safe level of exposure to hormone-disrupting chemicals.[863]

- May 11, 2014 – According to the GAO, the federal government is failing to inspect thousands of oil and gas wells located on public land, including those that pose special risks of water contamination or other environmental damage. An investigation by the Associated Press found that the Bureau of Land Management "had failed to conduct inspections on more than 2,100 of the 3,702 wells that it had specified as 'high priority' and drilled from 2009 through 2012. The agency considers a well 'high priority' based on a greater need to protect against possible water contamination and other environmental safety issues."[864]

- March 25, 2014 – An industry-funded study of oil and gas well integrity found that more than six percent of wells in a major shale exploration region in Pennsylvania showed evidence of leaking and conceded that this number is likely an underestimate. Researchers concluded that the percentage of wells with some form of well barrier or integrity failure is highly variable and could be as high as 75 percent. A separate analysis in the same study found 85 examples of cement or casing failures in Pennsylvania wells monitored between 2008 and 2011.[865]

- March 7, 2014 – In a comprehensive evaluation, Duke University scientists and colleagues reviewed the state of knowledge on possible effects of shale gas and hydraulic fracturing on water resources in the United States and concluded, "Analysis of published data (through January 2014) reveals evidence for stray gas contamination, surface water impacts in areas of intensive shale gas development, and the accumulation of radium isotopes in some disposal and spill sites."[866]

- February 19, 2014 – A Pennsylvania court found a gas corporation guilty of contaminating a woman's drinking water well in Bradford County. Methane levels after

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[863] Endocrine Society, "Hormone-Disrupting Activity of Fracking Chemicals Worse than Initially Found," *Science Daily*, June 23, 2014, http://www.sciencedaily.com/releases/2014/06/140623103939.htm?utm_source=feedburner&utm_medium=email&utm_campaign=Feed%3A+sciencedaily%2Ftop_news%2Ftop_health+%28ScienceDaily%3A+Top+Health+News%29.

[864] Hope Yen, "Fed Govt Failed to Inspect Higher Risk Oil Wells," *Pittsburgh Post-Gazette*, May 11, 2014, https://www.post-gazette.com/business/powersource/2014/05/11/Fed-govt-failed-to-inspect-higher-risk-oil-wells-2/stories/201405110198.

[865] R. J. Davies et al., "Oil and Gas Wells and Their Integrity: Implications for Shale and Unconventional Resource Exploitation," *Marine and Petroleum Geology* 56 (2014): 239–54, https://doi.org/10.1016/j.marpetgeo.2014.03.001.

[866] Avner Vengosh et al., "A Critical Review of the Risks to Water Resources From Unconventional Shale Gas Development and Hydraulic Fracturing in the United States," *Environmental Science & Technology* 48, no. 15 (2014): 8334–48, https://doi.org/10.1021/es405118y.

fracking were 1,300-2,000 times higher than baseline, according to the court brief. Iron levels and turbidity had also increased. The brief stated, "In short, Jacqueline Place lived for ten months deprived totally of the use of her well, and even after its 'restoration,' has been burdened with a water supply with chronic contamination, requiring constant vigilance and ongoing monitoring."[867]

- January 16, 2014 – Data from the Colorado Oil and Gas Conservation Commission showed that fracking-related chemical spills in Colorado exceed an average rate of one spill per day. Of the 495 chemical spills that occurred in that state over a one-year period of time, nearly a quarter impacted ground or surface water. Sixty-three of the spills spread within 1,500 feet of pigs, sheep, and cows; 225 spread within 1,500 feet of buildings.[868]

- January 10, 2014 – Duke University water tests revealed ongoing water contamination in Parker County, Texas, providing evidence that the EPA had prematurely ended its prior investigation into the water contamination.[869]

- January 5, 2014 – An Associated Press investigation into drinking water contamination from fracking in four states—Pennsylvania, Ohio, West Virginia, and Texas—found many cases of confirmed water contamination and hundreds more complaints. The Associated Press noted that their analysis "casts doubt on industry view that it rarely happens."[870]

- December 24, 2013 – A report from the EPA Inspector General concluded that evidence of fracking-related water contamination in Parker County, Texas was sound and faulted the EPA for prematurely ending its investigation there, relying on faulty water testing data from the gas industry in doing so, and failure to intervene when affected residents' drinking water remained unsafe.[871] As reported by *Business Insider*, "The EPA Screwed Up When It Dropped This Fracking Investigation."[872]

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[867] Brendan Gibbons, "Another 'Documented' Case! American Arbitration Association, Commercial Arbitration Tribunal, Orders Chesapeake to Pay Jacqueline Place of Terry Township, Bradford County PA, $60,000 for Temporary Methane Contamination in Water Well After Hydraulic Fracturing," *The Daily Review*, February 19, 2014, https://www.ernstversusencana.ca/american-arbitration-association-commercial-arbitration-tribunal-orders-chesapeake-to-pay-jaqueline-place-of-terry-township-bradford-county-pa-60000-for-methane-contamination-of-water-after-fracing/.

[868] John Tomasic, "Colorado Drilling Data: More than a Spill a Day," *The Colorado Independent*, January 16, 2014, http://www.coloradoindependent.com/145629/colorado-drilling-data-more-than-a-spill-a-day.

[869] Mark Drajem, "Duke Fracking Tests Reveal Dangers Driller's Data Missed," *Bloomberg*, January 9, 2014, http://www.bloomberg.com/news/2014-01-10/epa-s-reliance-on-driller-data-for-water-irks-homeowners.html.

[870] Kevin Begos, "4 States Confirm Water Pollution From Drilling," *USA Today*, January 5, 2014, http://www.usatoday.com/story/money/business/2014/01/05/some-states-confirm-water-pollution-from-drilling/4328859/.

[871] Neela Banerjee, "EPA Report on Fracking in Texas Raises New Concerns," *Los Angeles Times*, December 24, 2013, http://www.latimes.com/nation/la-na-epa-fracking-20131225,0,6042944.story#ixzz2oVB9FXVY.

[872] Douwe Miedema, "The EPA Screwed Up When It Dropped This Fracking Investigation," *Insider*, December 25, 2013, http://www.businessinsider.com/epa-criticized-for-dropping-fracking-investigation-2013-12.

- December 16, 2013 – Lead by Susan Nagel of the University of Missouri School of Medicine, researchers documented endocrine-disrupting properties in chemicals commonly used as ingredients of fracking fluid and found similar endocrine-disrupting activity in groundwater and surface water samples collected near drilling and fracking sites in Garfield County, Colorado. Endocrine disruptors are chemicals that interfere with the activity of hormones in the body and, at very low concentrations, can raise the risk of reproductive, metabolic, and neurological disorders, especially when exposures occur in early life. [873, 874, 875]

- December 7, 2013 – Reporting on the second gas leak at a single gas well in one month, the Fort Worth *Star-Telegram* uncovered another inherent risk of fracking for groundwater contamination: Silica sand, which is used as an ingredient in fracking fluid for its ability to prop open the shale fractures, can damage steel pipes as it flows back up the well along with the gas. According to Dan Hill, head of the petroleum engineering department at Texas A&M University, new wells are the most susceptible to sand erosion because "the amount of sand and gas rushing through valves and flow lines is at its greatest when a well first goes into production."[876]

- November 26, 2013 – A USGS report found serious impacts of fracking on watersheds and water quality throughout the Appalachian Basin, as well as issues with radiation and seismic events. As noted in the report, the knowledge of how extraction affects water resources has not kept pace with the technology.[877] Meanwhile, clean fresh water is becoming an increasingly scant resource. A report prepared for the U.S. State Department forecasts a serious freshwater shortage by 2030, with global demand exceeding supply by 40 percent.[878]

- November 22, 2013 – A USGS study of pollution from oil production in North Dakota, where horizontal drilling and hydraulic fracturing are heavily used, identified two potential plumes of groundwater contamination covering 12 square miles. The cause was traced to a casing failure in a wastewater disposal well. Drilling companies had incorrectly assumed that, once injected underground, the wastewater would remain contained. According to *EnergyWire*, the development of the Bakken oil formation is

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[873] Christopher C. Kassotis et al., "Estrogen and Androgen Receptor Activities of Hydraulic Fracturing Chemicals and Surface and Ground Water in a Drilling-Dense Region," *Endocrinology*, 2013, https://doi.org/10.1210/en.2013-1697.
[874] Banerjee, N. (2013, December 16). Hormone-disrupting chemicals found in water at fracking sites. *Los Angeles Times*. Retrieved from http://articles.latimes.com/2013/dec/16/science/la-sci-fracking-health-20131217
[875] Endocrine Society, "Fracking Chemicals Disrupt Hormone Function," *Science Daily*, December 16, 2013, www.sciencedaily.com/releases/2013/12/131216140428.htm.
[876] Caty Hirst and Jim Fuquay, "Second Leak Reported at East Fort Worth Gas Well Site," *Fort Worth Star-Telegram*, December 7, 2013, https://www.star-telegram.com/news/local/fort-worth/article3839099.html.
[877] William M. Kappel, John H. Williams, and Zoltan Szabo, "Water Resources and Shale Gas/Oil Production in the Appalachian Basin—Critical Issues and Evolving Developments" (U.S. Geological Survey, August 2013), http://pubs.usgs.gov/of/2013/1137/pdf/ofr2013-1137.pdf.
[878] National Intelligence Council, "Global Water Security," Intelligence Community Assessment, February 2, 2012, http://www.dni.gov/files/documents/Special%20Report_ICA%20Global%20Water%20Security.pdf.

"leaving behind an imprint on the land as distinct as the ones left by the receding ice sheets of the ice age."[879]

- October 25, 2013 – An Associated Press investigation uncovered nearly 300 oil pipeline spills in North Dakota in the previous ten months, all with no public notification. These were among some 750 "oil field incidents" that had occurred in the state over the same time period, also without public notification. Until the AP inquiry, industry and state officials had kept quiet about one particular "massive spill" that had been accidentally discovered by a wheat farmer. Even small spills can contaminate water sources permanently and take cropland out of production.[880]

- September 10, 2013 – Pennsylvania Attorney General Kathleen Kane filed criminal charges against Exxon Mobil Corporation's subsidiary, XTO Energy Corporation, for a spill of 50,000 gallons of toxic drilling wastewater in 2010 that contaminated a spring and a tributary of the Susquehanna River. In July, XTO settled civil charges for the incident without admitting liability by agreeing to pay a $100,000 fine and improve its wastewater management.[881]

- September 10, 2013 – Out of concern for risks posed to drinking water in the nation's capital, George Hawkins, General Manager of DC Water, Washington, DC's local water provider, called for a prohibition on horizontal drilling and hydraulic fracturing in the George Washington National Forest until the process can be proven safe.[882] The Potomac River is the source of the District's water supply and has its headwaters in the George Washington National Forest, which sits atop the Marcellus Shale. The general managers of Fairfax Water, provider of drinking water for Fairfax County, Virginia, and the U.S. Army Corps of Engineers have called for a similar prohibition.[883]

- August 28, 2013 – A joint USGS and U.S. Fish and Wildlife Service study documented a causal link between a fracking wastewater spill and the widespread death of fish in the Acorn Fork, a creek in Kentucky.[884]

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[879] Gayathri Vaidyanathan, "Bakken Shale: As Oil Production Sets in, Pollution Starts to Migrate -- Scientists," *E&E News*, November 22, 2013, https://web.archive.org/web/20131212051756/http://www.eenews.net/stories/1059990892.

[880] James MacPherson, "AP News Break: Nearly 300 Oil Pipeline Spills Went Unreported to US State Since 2012," *Canadian Business*, October 25, 2013, https://www.canadianbusiness.com/business-news/ap-newsbreak-nearly-300-oil-pipeline-spills-went-unreported-to-north-dakota-public-since-2012/.

[881] Andrew Maykuth, "Shale Criminal Charges Stun Drilling Industry," *The Philadelphia Inquirer*, September 12, 2013, https://www.inquirer.com/philly/business/20130912_AG_s_criminal_charges_stun_drilling_industry.html.

[882] George Hawkins, "Letter from George Hawkins, General Manager, DC Water, to U.S. Secretary of Agriculture, Thomas Vilsack," September 10, 2013, https://www.documentcloud.org/documents/798238-gwforestdcwaterletter.html.

[883] Aaron Wiener, "DC Water Chief Urges Agriculture Secretary Not to Allow Fracking Near D.C.," *Washington City Paper*, September 20, 2013, http://www.washingtoncitypaper.com/blogs/housingcomplex/2013/09/20/dc-water-chief-urges-agriculture-secretary-not-to-allow-fracking-near-d-c/.

[884] D. Papoulias and T. MacKenzie, "Hydraulic Fracturing Fluids Likely Harmed Threatened Kentucky Fish Species," *USGS Newsroom*, August 28, 2013, https://www.usgs.gov/news/hydraulic-fracturing-fluids-likely-harmed-threatened-kentucky-fish-species.

- July 25, 2013 – A University of Texas at Arlington study of drinking water found elevated levels of arsenic and other heavy metals in some samples from private drinking water wells located within five kilometers of active natural gas wells in the Barnett Shale.[885]

- July 3, 2013 – *ProPublica* reported that the EPA was wrong to have halted its investigation of water contamination in Wyoming, Texas and Pennsylvania—where high levels of benzene, methane, arsenic, oil, methane, copper, vanadium, and other chemicals associated with fracking operations have been documented.[886] Although numerous organizations and health professionals around the country have since called on the agency to resume its investigation, no action was taken.

- June 6, 2013 – Reviewing hundreds of regulatory and legal filings, *Bloomberg News* reported that drillers have offered out-of-court cash settlements and property buyouts to homeowners who claim that fracking ruined their water. These agreements typically come with gag orders and sealed records. This strategy, the investigation noted, allows the industry to continue claiming that no cases of water contamination due to fracking have ever been confirmed, impedes public health research, and shields data from regulators, policy makers, and the new media.[887] The EPA also long ago noted how non-disclosure agreements between oil and gas operators and landowners challenge scientific progress and keep examples of drilling harm secret from the public. In a 1987 report, the EPA wrote, "In some cases, even the records of well-publicized damage incidents are almost entirely unavailable for review. In addition to concealing the nature and size of any settlement entered into between the parties, impoundment curtails access to scientific and administrative documentation of the incident."[888]

- June 3, 2013 – A study by Duke University researchers linked fracking with elevated levels of methane, ethane, and propane in nearby groundwater.[889] Published in *Proceedings of the National Academy of Sciences*, the study included results from 141 northeastern Pennsylvania water wells. Methane levels were, on average, six times higher

[885] Brian E. Fontenot et al., "An Evaluation of Water Quality in Private Drinking Water Wells Near Natural Gas Extraction Sites in the Barnett Shale Formation," *Environmental Science & Technology* 47, no. 17 (2013): 10032–40, https://doi.org/10.1021/es4011724.
[886] Abrahm Lustgarten, "EPA's Abandoned Wyoming Fracking Study One Retreat of Many," *ProPublica*, July 3, 2013, http://www.propublica.org/article/epas-abandoned-wyoming-fracking-study-one-retreat-of-many.
[887] J. Efstathiou Jr. and Mark Drajem, "Drillers Silence Fracking Claims with Sealed Settlements," *Bloomberg*, June 5, 2013, http://www.bloomberg.com/news/2013-06-06/drillers-silence-fracking-claims-with-sealed-settlements.html.
[888] Environmental Protection Agency, "Management of Wastes from the Exploration, Development, and Production of Crude Oil, Natural Gas, and Geothermal Energy (Vol. 2 of 3: Geothermal Energy)," Report to Congress (U. S. Environmental Protection Agency, December 1987), Report to Congress: Management of wastes from the exploration, development, and production of crude oil, natural gas, and geothermal energy.
[889] Robert B. Jackson et al., "Increased Stray Gas Abundance in a Subset of Drinking Water Wells Near Marcellus Shale Gas Extraction," *Proceedings of the National Academy of Sciences* 110, no. 28 (2013): 11250–55, https://doi.org/10.1073/pnas.1221635110.

in drinking water wells closer to drilling sites when compared with those farther away, while ethane was 23 times higher.[890]

- May 19, 2013 – In Pennsylvania, the *Scranton Times-Tribune* released details of an investigation that revealed at least 161 cases of water contamination from fracking between 2008 and the fall of 2012, according to state Department of Environmental Protection records.[891]

- April 2013 – Researchers analyzing publicly available Colorado data found 77 surface spills impacting groundwater in Weld County alone. Samples of these spills often exceeded drinking water maximum contaminant levels (MCLs) for benzene, toluene, ethylbenzene and xylene; for benzene, a known carcinogen, 90 percent of the samples exceeded the legal limit.[892]

- March 4, 2013 – Researchers at the University of Pittsburgh Graduate School of Public Health analyzed samples of gas drilling wastewater discharged to surface water through wastewater treatment plants. Barium, strontium, bromides, chlorides, and benzene all exceeded levels known to cause human health impacts.[893]

- December 8, 2012 – State data in Colorado showed more than 350 instances of groundwater contamination resulting from more than 2,000 spills from oil and gas operations over the past five years. Further, as the *Denver Post* reported, "Contamination of groundwater—along with air emissions, truck traffic and changed landscapes—has spurred public concerns about drilling along Colorado's Front Range."[894]

- May 4, 2012 – A report for the Canadian Government, released under the Access to Information Act, reviewed the process, the regulatory framework globally, and the potential health hazards related to shale gas extraction. Additionally, the report evaluated mechanisms for potential impacts and summarized the data knowledge and data gaps. Regarding water contamination, the report determined, "Although quantitative data are lacking, the qualitative data available indicate that potential contamination of water related to the shale gas industry may present hazard to the public health, especially for local population." Regarding air contamination: "air emissions related to the shale gas

[890] CBS/AP, "Methane Found in Pa. Drinking Water Near Fracked Wells," *CBS News*, June 25, 2013, http://www.cbsnews.com/news/methane-found-in-pa-drinking-water-near-fracked-wells/.
[891] Laura Legere, "Sunday Times Review of DEP Drilling Records Reveals Water Damate, Murky Testing Methods," *The Times-Tribune*, May 18, 2013, http://thetimes-tribune.com/news/sunday-times-review-of-dep-drilling-records-reveals-water-damage-murky-testing-methods-1.1491547.
[892] Sherilyn A. Gross et al., "Analysis of BTEX Groundwater Concentrations from Surface Spills Associated With Hydraulic Fracturing Operations," *Journal of the Air & Waste Management Association* 63, no. 4 (2013): 424–32, https://doi.org/10.1080/10962247.2012.759166.
[893] Kyle J. Ferrar et al., "Assessment of Effluent Contaminants from Three Facilities Discharging Marcellus Shale Wastewater to Surface Waters in Pennsylvania," *Environmental Science & Technology* 47, no. 7 (2013): 3472–81, https://doi.org/10.1021/es301411q.
[894] Bruce Finley, "Drilling Spills Reaching Colorado Groundwater; State Mulls Test Rules," *The Denver Post*, December 8, 2012, sec. Environment, http://www.denverpost.com/environment/ci_22154751/drilling-spills-reaching-colorado-groundwater-state-mulls-test#ixzz2EihHU2fg.

industry present health hazards since the air pollutants originating from the vehicles and engines fueled by diesel are toxic to the respiratory and cardiovascular systems and can cause premature mortality, volatile organic compounds have been associated to neurotoxicity and some of these compounds (e.g. benzene) as well as NORMs are known or possible human carcinogens." The report concluded, "Any step of shale gas exploration/exploitation may represent a potential source of drinking water and air contamination; Hydraulic fracturing and wastewater disposal were identified as the main potential sources of risk."[895]

- May 2012 – A report by researchers at Natural Resources Defense Council and Carnegie Mellon University found that the options available for dealing with fracking wastewater are inadequate to protect public health and the environment, resulting in increasing quantities of toxic wastewater as an ongoing problem without a good solution.[896]

- January 11, 2012 – The USGS reported that the Marcellus Shale is already highly fractured and that numerous fissures naturally occurring within the formation could potentially provide pathways for contaminants to migrate vertically into water supplies.[897]

- October 25, 2011 – After receiving new information from two companies, members of Congress updated their findings to show that between 2005 and 2009, oil and gas service companies injected 32.7 million gallons of diesel fuel or hydraulic fracturing fluids containing diesel fuel in wells in 20 states.[898]

- October 17, 2011 – Thomas P. Jacobus, General Manager of the U.S. Army Corps of Engineers' Washington Aqueduct, called for a prohibition on horizontal hydraulic fracturing in the George Washington National Forest because of concern that fracking poses risks to drinking water. The Washington Aqueduct—which provides drinking water to Washington, DC, Arlington County, Virginia, and Falls Church, Virginia—is supplied by the Potomac River, which has its headwaters in the George Washington National Forest that sits atop the Marcellus Shale. Jacobus said, "Enough study on the

[895] Séverine Louis, "Potential Health Hazards from Shale Gas Exploration and Exploitation" (Presented to Health Canada by SANEXEN Environmental Services; Document released under the (Canadian) Access to Information Act, May 4, 2012), https://www.ernstversusencana.ca/wp-content/uploads/2012-Health-Canada-Potential-Health-Hazards-from-Shale-Gas-Drinking-water-Ambient-Air-released-under-FOIP.pdf.
[896] Rebecca Hammer and Jeanne VanBriesen, "In Fracking's Wake: New Rules Are Needed to Protect Our Health and Environment from Contaminated Wastewater" (Natural Resources Defense Council, May 2012), http://www.nrdc.org/energy/files/fracking-wastewater-fullreport.pdf.
[897] U.S. Geological Survey, New York Water Science Center, "Comments on the Revised Draft Supplemental Generic Environmental Impact Statement," January 11, 2012, http://www.ewg.org/sites/default/files/report/ReviseddraftSGEIS_USGScomments_Version3_0.pdf.
[898] Henry A. Waxman, Edward J. Markey, and Diana DeGette, "The Honorable Lisa Jackson, Administrator, U.S. Environmental Protection Agency," Letter, October 25, 2011, https://www7.nau.edu/itep/main/iteps/ORCA/3934_ORCA.pdf.

technique [hydraulic fracturing] has been published to give us great cause for concern about the potential for degradation of the quality of our raw water supply…."[899]

- October 11, 2011 – Charles M. Murray, General Manager of Fairfax Water, called for a prohibition on horizontal hydraulic fracturing in the George Washington National Forest. "Natural gas development activities have the potential to impact the quantity and quality of Fairfax Water's source water," Murray wrote. "Downstream water users and consumers will bear the economic burden if drinking water sources are contaminated or the quality of our source water supply is degraded."[900] Fairfax Water provides drinking water for Fairfax County in Virginia.

- September 7, 2011 – In its draft Supplemental Generic Environmental Impact Statement (SGEIS), the New York State Department of Environmental Conservation (NYS DEC) acknowledged that "there is questionable available capacity"[901] for New York's public sewage treatment plants to accept drilling wastewater, yet the agency said that it would allow those facilities to accept such waste if the plants meet permitting conditions.[902] The NYS DEC proposed underground injection as one alternative to sewage treatment procession of fracking waste. Although it is a common method of disposal for fracking wastewater,[903] the last significant government study of pollution risks from oil and gas wastewater injection wells occurred in 1989 and found multiple cases of costly groundwater contamination.[904] In subsequent years, studies have continued to link underground injection of drilling wastewater to pollution as well as earthquakes.[905]

- September 2011 – A team led by Theo Colburn of the Endocrine Disruptor Exchange found that 25 percent of chemicals known to be used in fracking fluids are implicated in cancer, 37 percent could disrupt the endocrine system, and 40-50 percent could cause

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[899] Thomas P. Jacobus, "Draft Environmental Impact Statement for the George Washington National Forest," Letter to K. Landgraf, October 17, 2011, https://web.archive.org/web/20160305022532/http://www.svnva.org/wp-content/uploads/fairfax-wash-aquaduct-gwnf-comments.pdf.
[900] Charles M. Murray, "Draft Environmental Impact Statement for the George Washington National Forest," Letter to K. Landgraf, October 11, 2011, https://web.archive.org/web/20160305022532/http://www.svnva.org/wp-content/uploads/fairfax-wash-aquaduct-gwnf-comments.pdf.
[901] New York State Department of Environmental Conservation, "Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program, Well Permit Issuance for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs," Report 6-62, 2011.
[902] New York State Department of Environmental Conservation, "Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program, Well Permit Issuance for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs," Rep 6-57 through 6-63, 2011.
[903] New York State Department of Environmental Conservation, "Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program, Well Permit Issuance for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs," Report 6-64, 2011.
[904] U.S. Government Accountability Office, "Drinking Water: Safeguards Are Not Preventing Contamination From Injected Oil and Gas Wastes," July 5, 1989, http://www.gao.gov/products/RCED-89-97.
[905] Henry Fountain, "Disposal Halted at Well After New Quake in Ohio," *The New York Times*, January 1, 2012, sec. Environment, http://www.nytimes.com/2012/01/02/science/earth/youngstown-injection-well-stays-shut-after-earthquake.html.

nervous, immune and cardiovascular system problems. The research team also found that more than 75 percent could affect the skin, eyes, and respiratory system, resulting in various problems such as skin and eye irritation or flu-like symptoms.[906]

- August 3, 2011 – As reported by the *New York Times,* the EPA had alerted Congress in 1987 about a case of water contamination caused by fracking. Its report documented that a shale gas well hydraulically fractured at a depth of more than 4,200 feet contaminated a water supply only 400 feet from the surface.[907, 908, 909]

- May 18, 2011 – The state of Pennsylvania fined Chesapeake Energy Corporation $900,000 for an incident in which improper cementing and casing in one of the company's gas wells allowed methane to migrate underground and contaminate 16 private drinking water wells in Bradford County.[910]

- May 17, 2011 – A Duke University study documented "systematic evidence for methane contamination of drinking water associated with shale gas extraction."[911] The study showed that methane levels were 17 times higher in water wells near drilling sites than in water wells in areas without active drilling.[912]

- April 22, 2011 – Describing one of many blowouts, the Associated Press reported on a shale gas well in Canton, Pennsylvania that spewed thousands of gallons of chemical-laced water on farmland and into a stream for two consecutive days before being brought under control.[913]

- April 18, 2011 – As part of a year-long investigation into hydraulic fracturing and its potential impact on water quality, U.S. Representatives Henry Waxman (D-Calif.), Edward Markey (D-Mass.) and Diana DeGette (D-Colo.) released the second of two reports issued in 2011. Their analysis of hydraulic fracturing fluids used by the 14

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[906] Theo Colborn et al., "Natural Gas Operations from a Public Health Perspective," *Human and Ecological Risk Assessment: An International Journal* 17, no. 5 (2011): 1039–56, https://doi.org/10.1080/10807039.2011.605662.
[907] Ian Urbina, "A Tainted Water Well, and Concern There May Be More," *The New York Times*, August 3, 2011, http://www.nytimes.com/2011/08/04/us/04natgas.html.
[908] U.S. Environmental Protection Agency, "Management of Wastes from the Exploration, Development, and Production of Crude Oil, Natural Gas, and Geothermal Energy," Report to Congress, Sec. 4-22, 4-23, December 1987, http://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=20012D4P.PDF.
[909] Dusty Horwitt, "Cracks in the Façade" (Environmental Working Group, August 3, 2011), https://static.ewg.org/reports/2011/Cracks-in-the-Facade.pdf.
[910] Andrew Maykuth, "Pa. Fines Chesapeake Energy Corp. $1.1 Million for Drilling Violation," *The Philadelphia Inquirer*, May 18, 2011, https://www.inquirer.com/philly/news/local/20110518_Pa__fines_Chesapeake_Energy_Corp___1_1_million_for_drilling_violation_1.html.
[911] Stephen G. Osborn et al., "Methane Contamination of Drinking Water Accompanying Gas-Well Drilling and Hydraulic Fracturing," *Proceedings of the National Academy of Sciences* 108, no. 20 (2011): 8172–76, https://doi.org/10.1073/pnas.1100682108.
[912] Duke University, "Methane Levels 17 Times Higher in Water Wells Near Hydrofracking Sites, Study Finds," Press Release (Science Daily, May 10, 2011), http://www.sciencedaily.com/releases/2011/05/110509151234.htm.
[913] The Associated Press, "Crews Stop Flow of Drilling Fluid From Pennsylvania Well," *Syracuse.Com*, April 22, 2011, http://www.syracuse.com/news/index.ssf/2011/04/crews_stop_flow_of_drilling_fl.html.

leading oil and natural gas service companies between 2005 and 2009 found, among other things, that the companies used more than 650 different products that contained chemicals that are known or possible human carcinogens, regulated under the Safe Drinking Water Act, or listed as hazardous air pollutants under the Clean Air Act. The report also showed that "between 2005 and 2009, the companies used 94 million gallons of 279 products that contained at least one chemical or component that the manufacturers deemed proprietary or a trade secret … in most cases the companies stated that they did not have access to proprietary information about products they purchased 'off the shelf' from chemical suppliers. In these cases, the companies are injecting fluids containing chemicals that they themselves cannot identify."[914] These findings were reported in the *New York Times*.[915]

- January 2011 – A team of scientists led by a University of Central Arkansas researcher called attention to the threat posed to surface waters by rapidly expanding shale gas development, noting a lack of data collection accompanying the rush to drill. "Gas wells are often close to surface waters that could be impacted by elevated sediment runoff from pipelines and roads, alteration of stream flow as a result of water extraction, and contamination from introduced chemicals or the resulting wastewater."[916]

- January 31, 2011 – As part of a year-long investigation into hydraulic fracturing and its potential impact on water quality, U.S. Representatives Henry Waxman (D-Calif.), Edward Markey (D-Mass.) and Diana DeGette (D-Colo.) reported that "between 2005 and 2009, oil and gas service companies injected 32.2 million gallons of diesel fuel or hydraulic fracturing fluids containing diesel fuel in wells in 19 states." Furthermore, revealing apparent widespread violation of the Safe Drinking Water Act, the investigation found that no oil and gas service companies had sought—and no state or federal regulators had issued—permits for the use of diesel fuel in hydraulic fracturing.[917]

- April 29, 2010 – In 2010, the Colorado Oil and Gas Conservation Commission fined Occidental Petroleum Corporation (OXY) USA a record $390,000 for an incident of pollution, discovered in 2008, when its drilling wastes leaked through an unlined pit, contaminated two springs with benzene, and polluted other nearby water sources. In addition, the regulators separately fined OXY USA $257,400 for a nearby case of

[914] Henry A. Waxman, Edward J. Markey, and Diana DeGette, "Chemicals Used in Hydraulic Fracturing" (United States House of Representatives Committee on Energy and Commerce Minority Staff, April 18, 2011), http://democrats.energycommerce.house.gov/sites/default/files/documents/Hydraulic-Fracturing-Chemicals-2011-4-18.pdf.
[915] Ian Urbina, "Chemicals Were Injected Into Wells, Report Says," *The New York Times*, April 17, 2011, http://www.nytimes.com/2011/04/17/science/earth/17gas.html.
[916] Sally Entrekin et al., "Rapid Expansion of Natural Gas Development Poses a Threat to Surface Waters," *Frontiers in Ecology and the Environment* 9, no. 9 (2011): 503–11, https://doi.org/10.1890/110053.
[917] Amy Mall, "Hydraulic Fracturing Has Used Diesel Fuel in 19 States; 'Appears to Be a Violation of the Safe Drinking Water Act,'" NRDC, *Expert Blog* (blog), January 31, 2011, https://www.nrdc.org/experts/amy-mall/hydraulic-fracturing-has-used-diesel-fuel-19-states-appears-be-violation-safe.

pollution, also discovered in 2008, in which a torn liner in a pit caused drilling waste fluids to leak out and contaminate two springs with benzene.[918]

- June 4, 2009 – A leaking pipe carrying fracking waste in Washington County, Pennsylvania, polluted a tributary of Cross Creek Lake, killing fish, salamanders, crayfish, and aquatic insect life in approximately three-quarters of a mile of the stream.[919]

- April 26, 2009 – Officials in three states linked water contamination and methane leaks to gas drilling. Incidents included a case in Ohio where a house exploded after gas seeped into its water well and multiple cases of exploding drinking water wells in Dimock, Pennsylvania.[920]

- November 13, 2008 – *ProPublica* reported more than 1,000 cases of drilling-related contamination documented by courts and state and local governments in Colorado, New Mexico, Alabama, Ohio, and Pennsylvania.[921]

- September 1, 2008 – In Bainbridge, Ohio, a gas well that was improperly cemented and subsequently fractured by Ohio Valley Energy Systems Corporation allowed natural gas to migrate outside of the well, causing a home to explode. In addition, 23 nearby water wells were contaminated, two of which were located more than 2,300 feet from the drilling site.[922, 923, 924]

[918] Dennis Webb, "Record Fine, Second One Against Oxy Approved," *The Daily Sentinel*, April 29, 2011, https://www.gjsentinel.com/breaking/breaking_news/record-fine-second-one-against-oxy-approved/article_ef661e6a-60db-52be-a4f1-0ad99363af72.html.
[919] Pittsburg Post-Gazette, "Waste from Marcellus Shale Drilling in Cross Creek Park Kills Fish," *Pittsburgh Post-Gazette*, June 4, 2009, http://www.post-gazette.com/washington/2009/06/05/Waste-from-Marcellus-shale-drilling-in-Cross-Creek-Park-kills-fish/stories/200906050136.
[920] Abrahm Lustgarten, "Officials in Three States Pin Water Woes on Gas Drilling," *ProPublica*, April 26, 2009, http://www.propublica.org/article/officials-in-three-states-pin-water-woes-on-gas-drilling-426.
[921] Abrahm Lustgarten, "Buried Secrets: Is Natural Gas Drilling Endangering U.S. Water Supplies?," *ProPublica*, 2008, http://www.propublica.org/article/buried-secrets-is-natural-gas-drilling-endangering-us-water-supplies-1113.
[922] Ohio Department of Natural Resources, "Report on the Investigation of the Natural Gas Invasion of Aquifers in Bainbridge Township of Geauga County, Ohio," Report on the Bainbridge Investigation (Oil Department of Natural Resources, Division of Mineral Resources Management, September 1, 2008), https://marcellus-wv.com/online-courses/well_construction/report.pdf.
[923] E. S. Bair, D. C. Freeman, and J. M. Senko, "Expert Panel Technical Report, Subsurface Gas Invasion Bainbridge Township, Geauga County, Ohio," June 2010, https://web.archive.org/web/20150703190148/http://oilandgas.ohiodnr.gov/portals/oilgas/pdf/bainbridge/DMRM%200%20Title%20Page,%20Preface,%20Acknowledgements.pdf.
[924] Ohio Department of Natural Resources, "Order Number 2009-17," April 14, 2009.

Inherent engineering problems that worsen with time

Studies show that many oil and gas wells leak, allowing for the migration of natural gas and potentially other substances into groundwater and/or the atmosphere. About five percent of wells leak immediately, 50 percent leak after 15 years, and 60 percent leak after 30 years. The act of fracking itself can redistribute stress and open underground pathways for fluid migration, which, in turn, can communicate with other pathways created during the fracking of neighboring wells, by the deterioration of cement in aging well casings, or by earthquakes, leading in all cases to the risk of groundwater contamination and atmospheric emissions. The injection of fracking waste into subterranean rock formations can also intersect with active and abandoned wells in ways that allow vertical migration of toxic fluids and vapors.

The problem of leaking wells, first identified by industry, has no known solution. Data from Pennsylvania's Department of Environmental Protection (DEP) agree, showing over nine percent of shale gas wells drilled in the state's northeastern counties leaking within the first five years. Leaks pose serious risks, including potential loss of life or property from explosions and migration of gas and other harmful chemicals into drinking water supplies. Methane leaking into aquifers can, under some conditions, be transformed by bacteria into hydrogen sulfide and other poisonous byproducts. Microbes from deep shale formations can likewise generate sulfides contributing, over time, to corrosion of pipes and casings.

There is no evidence to suggest that the problem of cement and well casing impairment is abating. Industry has no solution for rectifying the chronic problem of well casing/cement failures and resulting leakage. Plugging old, inactive wells is an imperfect solution because, as research shows, the cement plugs themselves degrade over time and because many wells leak from outside the well casing.

- February 5, 2021 – Fracking wastewater gushed for four days from an unplugged oil and gas well in southeastern Ohio (Noble County) that had been idle since 2012. The fluid is thought to have migrated from nearby fracking waste injection wells, of which there are at least nine in the county. Six were active at the time of the gusher.[925]

- September 5, 2020 – Fracking wastewater from an underground injection well in southeastern Ohio (Washington County) migrated to gas-producing wells five miles away, according to the Ohio Department of Natural Resources. The fracking waste was detected in 28 gas wells.[926]

- February 1, 2020 – Researchers studied possible interconnections between wells on adjacent and nearby pads to assess the potential for such wells to communicate through

[925] Beth Burger, "Thousands of Gallons of Fracking Waste Spilled from Noble County Well for Four Days," *The Columbus Dispatch*, February 5, 2021, https://www.dispatch.com/story/news/2021/02/04/thousands-gallons-flthousands-of-gallouid-spilled-oil-and-gas-well-noble-co-damage-and-cause-unclear/4397912001/.
[926] Beth Burger, "State Investigating Whether Injection Well Waste Affecting Drinking Water," *The Columbus Dispatch*, September 5, 2020, https://www.dispatch.com/story/news/local/2020/09/05/state-investigating-whether-injection-well-waste-affecting-drinking-water/113667974/.

fracture-like pathways. Results from microseismic data, chemical and radioactive tracers, and production interference (volume and pressure measurements) confirm communication among wells at distances up to 1200 meters (0.75 miles) horizontally and 164 meters (0.10 miles) vertically (crossing shale boundary layers) and lasting for up to 1.7 years. The intensive well communication over long distances appeared to be due to reactivation of natural faults or fractures, in addition to fractures propagating into pre-existing hydraulic fractures. Since fracture height is "generally assumed as formation thickness, neglecting the possibility of fracture growth beyond the target shale formations," these results challenge existing understandings of the fracturing process, provide support for claims of contamination by fracking fluids of aquifers outside target formations, and suggest the need for set-backs of at least 1200 meters to protect subsurface water resources near fracking sites.[927]

- November 27, 2019 – To gauge the extent of possible contamination of air and water resources by subsurface leakage from oil and gas wells, Canadian researchers used ArcGIS to perform cluster analysis and identify "hot spots" where high densities of oil and gas wells (both active and abandoned) overlap with high densities of earthquake activity in California, Oklahoma, and British Columbia. The well-documented catastrophic leakage of gases from the Aliso Canyon Natural Gas Storage Field corresponds to one of the identified hot spots. Of note, a comparison of known major fault locations with earthquake clusters shows that "there are regions in each province/state where a major fault is not mapped but an earthquake cluster exists."[928]

- April 19, 2018 – As part of a major review, a University of Aberdeen team of researchers assessed the various underground pathways by which fracking creates methane leaks and concluded that aging well casings are a leading cause of methane leaks from drilling and fracking operations. While the intersection of fracture propagation with naturally present geological faults in the subsurface is another potential route for methane leakage, the more important route is the intersection of fracture propagation with other wells with old cement. "The major sources of methane leakage related to shale gas activities are the intersections of hydraulic fractures with abandoned oil and gas wells which have a reduced mechanical well integrity due to cement degradation. As a result, the stress redistributions caused by hydraulic fracturing and the deterioration of cement in abandoned wells with age allow migration pathways to be created easily, leading to both groundwater contamination and atmospheric emissions." Plugging wells is an imperfect solution because the cement commonly used for this process itself degrades with time, especially in the presence of carbon dioxide. "No concrete method [has been] established for the methane leakage mitigation from shale gas wells."[929]

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[927] Yingkun Fu and Hassan Dehghanpour, "How Far Can Hydraulic Fractures Go? A Comparative Analysis of Water Flowback, Tracer, and Microseismic Data From the Horn River Basin," *Marine and Petroleum Geology* 115 (2020): 104259, https://doi.org/10.1016/j.marpetgeo.2020.104259.
[928] Mary Kang et al., "Potential Increase in Oil and Gas Well Leakage Due to Earthquakes," *Environmental Research Communications* 1, no. 12 (2019): 121004, https://doi.org/10.1088/2515-7620/ab576e.
[929] Azis Yudhowijoyo et al., "Subsurface Methane Leakage in Unconventional Shale Gas Reservoirs: A Review of Leakage Pathways and Current Sealing Techniques," *Journal of Natural Gas Science & Engineering* 54 (2018): 309–19, https://doi.org/10.1016/j.jngse.2018.04.013.

- November 23, 2017 – An investigative journalist from *The Tyee* in Vancouver obtained a copy of a 2013 report from British Columbia's Oil and Gas Commission warning about hundreds of uncontrolled methane leaks from shale gas wells located in the northern Rocky Mountain range near Fort Nelson. The commission's report, never shared with the public or with elected officials, remained an internal document until it was uncovered by the newspaper. Cornell University engineer Anthony Ingraffea, quoted in the story, said the report's findings served as another confirmation that wells leak badly and inevitably over time. "What do they expect from underground operations such as these, total obedience to design intent? Why are operators and regulators around the world seemingly surprised when things go wrong underground, and in so many ways, and so often?" Ingraffea said.[930, 931]

- July 5, 2017 – A team of researchers led by microbiologists from Ohio State University investigated bacteria from hydraulically fractured shale by sampling fracking wastewater from a well drilled in the Utica shale. The dominant microorganism was a bacterium that generates sulfides, which can contribute to corrosion of well casings. "The impact of microbial metabolism within these environments is poorly understood. . . . These findings emphasize the potential detrimental effects that could arise from thiosulfate-reducing microorganisms in hydraulically fractured shales, which are undetected by current industry-wide corrosion diagnostics."[932]

- April 1, 2017 – The rapid depletion of fracked wells requires drilling ever more wells to keep up with production. As time goes by, wells become more densely packed into a drilling section. Decreasing distances between wells increases the risk of inter-well communication, which occurs when the pumping of fracking fluid into one well affects a nearby well. According to an analysis in the *Journal of Petroleum Technology*, these so called "frack hits" are unpredictable, uncontrolled, and can be violent, damaging tubing, casings, and well integrity. In some cases, frack hits involve blowouts of fracking fluid. The industry has no solution for this increasingly common problem.[933] Indeed, as a sequel report describes, operators use frack hits as a tool for revealing how tightly wells can be spaced in a drilling section to maximize extraction—even while acknowledging inherent safety risks. A drilling section with no frack hits at all is presumed to lack sufficient well density for optimal "economic recovery."[934]

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[930] Andrew Nikiforuk, "Despite What Politicians Say, Hundreds of BC Gas Wells Leak Methane," *The Tyee*, November 23, 2017, https://thetyee.ca/News/2017/11/23/Hundreds-of-BC-Gas-Wells-Leak-Meth/.
[931] BC Oil and Gas Commission, "Gas Mitration Preliminary Investigation Report," December 2013, https://www.bcogc.ca/node/14620/download.
[932] Anne E. Booker et al., "Sulfide Generation by Dominant Halanaerobium Microorganisms in Hydraulically Fractured Shales," *mSphere* 2, no. 4 (2017): e00257-17, https://doi.org/10.1128/mSphereDirect.00257-17.
[933] Trent Jacobs, "Oil and Gas Producers Find Frac Hits in Shale Wells a Major Challenge," *Journal of Petroleum Technology*, March 31, 2017, https://jpt.spe.org/oil-and-gas-producers-find-frac-hits-shale-wells-major-challenge#:~:text=Risk%20management%20Oil%20and%20Gas%20Producers%20Find%20Frac,in%20oil%20and%20gas%20production.%20March%2031%2C%202017.
[934] Trent Jacobs, "Frac Hits Reveal Well Spacing May Be Too Tight, Completion Volumes Too Large," *Journal of Petroleum Technology*, October 31, 2017, https://jpt.spe.org/frac-hits-reveal-well-spacing-may-be-too-tight-completion-volumes-too-large.

- July 9, 2015 – As part of a larger examination of the potential health and environmental impacts of fracking in California, the California Council on Science and Technology (CCST) documented cases of well failures triggered by underground movements that caused well casings to shear. Sheared well casings can allow gas and fluids from the fracking zone to migrate to overlying aquifers. The CCST team identified several mechanisms by which casing shears can occur in California as oil wells age: surface subsidence, heaving, reservoir compaction, and earthquakes. Prolonged drought can also damage the integrity of well casings: as groundwater levels fall, landforms can sink and contribute to casing shear.[935]

- June 30, 2015 – According to the New York State Department of Environmental Conservation (NYS DEC) Findings Statement, "there is a risk that well integrity can fail, especially over time, and questions have arisen about whether high-volume hydraulic fracturing can cause seismic changes which could potentially result in fracturing fluid migration through abandoned wells or existing fissures and faults. Thus, high-volume hydraulic fracturing could result in significant adverse impacts to water resources from well construction and fracturing fluid migration."[936]

- June 4, 2015 – As part of a draft assessment of fracking's impact on drinking water, the U.S. Environmental Protection Agency (EPA) examined cases of water contamination across the United States and concluded that "construction issues, sustained casing pressure, and the presence of natural faults and fractures can work together to create pathways for fluids to migrate toward drinking water resources." Fracking older wells poses additional risks, the draft study notes, because aging itself "can contribute to casing degradation, which can be accelerated by exposure to corrosive chemicals, such as hydrogen sulfide, carbonic acid, and brines" and because many older wells were never designed to withstand the high pressures and stress of fracking operations. The EPA estimates that 6 percent of the 23,000 U.S. oil and gas wells (= 1,380 wells) first fracked in 2009 or 2010 were drilled more than ten years earlier.[937]

- December 2, 2014 – Problems with structural integrity have been documented in a well at the only hydraulically fractured site in the United Kingdom. Email messages obtained under freedom of information laws reveal that problems with wellbore integrity emerged in April of 2014 and attempts were made to remediate the problem, although nothing was reported at that time to regulators. The drilling company, Cuadrilla Resources, continues to deny that any problems exist with the well, emphasizing that "no leak of fluids"

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[935] William T. Stringfellow et al., "Chapter Two: Impacts of Well Stimulation on Water Resources," in *An Independent Scientific Assessment of Well Stimulation in California* (California Council on Science and Technology, 2015), https://ccst.us/wp-content/uploads/160708-sb4-vol-II-2-1.pdf.

[936] New York State Department of Environmental Conservation, "Final Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program: Regulatory Program for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs," Findings Statement (NYSDEC, June 2015), http://www.dec.ny.gov/docs/materials_minerals_pdf/findingstatehvhf62015.pdf.

[937] U.S. Environmental Protection Agency, "Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources," Executive Summary (Office of Research and Development, June 2015), http://www2.epa.gov/sites/production/files/2015-06/documents/hf_es_erd_jun2015.pdf.

occurred and that "the issue" was resolved during the abandonment process. Cuadrilla had previously been reprimanded for failing to disclose a more minor deformation in the well casing. The well was abandoned at the end of last year, following two earthquakes in 2011, which scientists determined to have been caused by fracking at the site.[938]

- August 11, 2014 – Researchers affiliated with multiple universities and with the Los Alamos National Laboratory summarized recent field observations of wellbore-integrity failure, concluding that, because at least some well failures are not identified, reported barrier failure rates of 1-10 percent of wells and reported rates of groundwater contamination of 0.01-0.1 percent of wells constitute a "lower bound" for possible environmental problems. Citing hydraulic fracturing, as well as temperature and pressure changes, as operations that can induce pathways for leaks, the authors point out that few studies have considered the very-long-term fate (">50 years") of wellbore systems. They include "whether unconventional resource development alters the frequency of well integrity failures" as a critical topic for future research.[939]

- July 30, 2014 – Based on records obtained from Pennsylvania's DEP, Scranton's *Times-Tribune* reported that five natural gas wells in Bradford County have leaked methane for years because of persistent casing and cement problems. In the most recent violation, a PA-DEP inspector found combustible gas flowing through vents connected to the cement between layers of pipe. The agency issued a notice of violation for each well, saying combustible gas outside the well's surface casing violates state regulations. Each of the wells has four layers of steel casing, but nothing prevents leaking (stray) methane from flowing into the atmosphere. No evidence of water contamination has yet been seen. None of the wells have produced any gas for sale.[940]

- June 30, 2014 – A study published in *Proceedings of the National Academy of Sciences* by a Cornell University research team projected that over 40 percent of shale gas wells in Northeastern Pennsylvania will leak methane into groundwater or the atmosphere over time. Analyzing more than 75,000 state inspections of more than 41,000 oil and gas wells in Pennsylvania since 2000, the researchers identified high occurrences of casing and cement impairments inside and outside the wells. A comparative analysis showed that newer, unconventional (horizontally fracked) shale gas wells were leaking at six times the rate of conventional (vertical) wells drilled over the same time period. The leak rate for unconventional wells drilled after 2009 was at least six percent, and rising with time. In the state's northeastern counties between 2000 and 2012, over nine percent of shale gas wells drilled leaked within the first five years.[941] The study also discovered that over 8,000 oil and gas wells drilled since 2000 had not received a facility-level inspection.

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[938] Ben Bryant, "The Only Fracked Site in the United Kingdom Suffered Structural Failure," *Vice News*, December 2, 2014, https://news.vice.com/article/the-only-fracking-site-in-the-united-kingdom-suffered-structural-failure.
[939] Robert B. Jackson et al., "The Environmental Costs and Benefits of Fracking," *Annual Review of Environment and Resources* 39 (2014): 327–62, https://doi.org/10.1146/annurev-environ-031113-144051.
[940] Brendan Gibbons, "Five Gas Wells Leaked Methane for Years," *The Times-Tribune*, April 15, 2020, http://thetimes-tribune.com/news/five-gas-wells-leaked-methane-for-years-1.1727537.
[941] Anthony R. Ingraffea et al., "Assessment and Risk Analysis of Casing and Cement Impairment in Oil and Gas Wells in Pennsylvania, 2000-2012," *Proceedings of the National Academy of Sciences U.S.A.*, June 30, 2014, http://www.pnas.org/content/early/2014/06/25/1323422111.abstract.

This study helps explain the results of earlier studies that documented elevated levels of methane in drinking water aquifers located near drilling and fracking operations in Pennsylvania and points to compromised structural integrity of well casings and cement as a possible mechanism.

- May 22, 2014 – In a 69-page report, University of Waterloo researchers warned that natural gas seeping from 500,000 wellbores in Canada represents "a threat to environment and public safety" due to groundwater contamination, greenhouse gas emissions, and explosion risks wherever methane collects in unvented buildings and spaces. The report found that 10 percent of all active and suspended gas wells in British Columbia now leak methane. Additionally, the report found that some hydraulically fractured shale gas wells in that province have become "super methane emitters" that spew as much as 2,000 kilograms of methane a year.[942, 943]

- May 1, 2014 – Following a comprehensive review of evidence, the Council of Canadian Academies identified inherent problems with well integrity as one of its top concerns about unconventional drilling and fracking. According to one expert panel, "the greatest threat to groundwater is gas leakage from wells from which even existing best practices cannot assure long-term prevention."[944] Regarding their concerns related to well integrity and cement issues, the panel wrote:

> Two issues of particular concern to panel members are water resources, especially groundwater, and GHG emissions. Both related to well integrity…. Natural gas leakage from improperly formed, damaged, or deteriorated cement seals is a long-recognized yet unresolved problem …. Leaky wells due to improperly placed cement seals, damage from repeated fracturing treatments, or cement deterioration over time, have the potential to create pathways for contamination of groundwater resources and to increase GHG emissions.

They further explain:

> Cement may crack, shrink, or become deformed over time, thereby reducing the tightness of the seal around the well and allowing the fluids and gases … to escape into the annulus between casing and rock and thus to the surface…. The challenge of ensuring a tight cement seal [will] be greater for shale gas wells that are subjected to repeated pulses of high pressure during the hydraulic fracturing process than for conventional gas wells. This pressure stresses the casing and therefore the cement that isolates the well from surrounding formations

[942] Maurice B. Dusseault, Richard E. Jackson, and Daniel MacDonald, "Towards a Road Map for Mitigating the Rates and Occurrences of Long-Term Wellbore Leakage" (Geofirma Engineering Ltd., May 22, 2014), http://geofirma.com/wp-content/uploads/2015/05/lwp-final-report_compressed.pdf.
[943] Andrew Nikiforuk, "Canada's 500,000 Leaky Energy Wells: 'Threat to Public,'" *The Tyee*, June 5, 2014, 000, http://www.thetyee.ca/News/2014/06/05/Canada-Leaky-Energy-Wells/.
[944] Council of Canadian Academies, "Environmental Impacts of Shale Gas Extraction in Canada: The Expert Panel on Harnessing Science and Technology to Understand the Environmental Impacts of Shale Gas Extraction," Scientific Publication, May 1, 2014, https://www.ccacoalition.org/en/resources/environmental-impacts-shale-gas-extraction-canada-expert-panel-harnessing-science-and.

repeatedly.

- January 8, 2013 – According to state inspections of all 6,000 wells drilled in Pennsylvania's Marcellus Shale before 2013, six to ten percent of them leaked natural gas, with the rate of leakage increasing over time. The rate was six percent in 2010 (97 well failures out of 1,609 wells drilled); 7.1 percent in 2011 (140 well failures out of 1,972 wells drilled); and 8.9 percent in 2012 (120 well failures out of 1,346 wells drilled).[945] These data include wells that were cited for leakage violations, and wells that were noted to be leaking by inspectors but which had not been given violations. The NYS DEC forecasts that 50,000 wells could be drilled over the life of the Marcellus Shale play. If they fail at the same rate as wells in Pennsylvania, 4,000 wells would fail and leak in New York almost immediately.[946]

- March 2009 – A study published by the Society of Petroleum Engineers of more than 315,000 oil, gas, and injection wells in Alberta, Canada, found that 4.5 percent of the wells had unintended gas flow to the surface. In one designated area, officials required testing for gas migration outside the well casings in addition to routine testing for gas leaks within the rings of steel casings (annuli). Within this special testing zone, 15.5 percent of wells (3,205 of 20,725) leaked gas, and the incidence of gas leaks was four times percent higher in horizontal or deviated wells than in vertical wells.[947]

- Autumn 2003 – Schlumberger, one of the world's largest companies specializing in hydraulic fracturing and other oilfield services, reported in its in-house publication, *Oilfield Review*, that more than 40 percent of approximately 15,500 wells in the outer continental shelf area in the Gulf of Mexico were leaking gas. These included actively producing wells, in addition to shut-in and temporarily abandoned wells. In many cases, the gas leaked through the spaces (annuli) between layers of steel casing that drilling companies had injected with cement precisely to prevent such gas leaks. Leakage rates increased dramatically with age: about five percent of the wells leaked immediately; 50 percent were leaking after 15 years; and 60 percent were leaking after about 30 years.[948] Gas leaks pose serious risks including loss of life from explosions and migration of gas and associated contaminants into drinking water supplies. Leaks also allow the venting of raw methane into the atmosphere where it acts as a powerful greenhouse gas.

- November 2000 – Maurice Dusseault, a specialist in rock mechanics at the University of Waterloo in Ontario, and two co-authors presented a paper published by the Society of Petroleum Engineers, in which they reported that oil and natural gas wells routinely leak

[945] Anthony R. Ingraffea, "Some Scientific Failings Within High Volume Hydraulic Fracturing Proposed Regulations 6 NYCRR Parts 550-556, 560, Comments and Recommendations Submitted to the NYS Dept. of Environmental Conservation" (PSE Healthy Energy, 2013).
[946] New York State Department of Environmental Conservation, "Supplemental Generic Environmental Impact Statement (SGEIS) on the Oil, Gas and Solution Mining Regulatory Program: Well Permit Issuance for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs" (NYSDEC, 2011), https://hero.epa.gov/hero/index.cfm/reference/details/reference_id/1777818.
[947] Theresa Watson and Stefan Bachu, "Evaluation Of The Potential For Gas And CO2 Leakage Along Wellbores," *Society of Petroleum Engineers Drilling & Completion* 24 (2009): 115–26, https://doi.org/10.21.18/106817-PA.
[948] Claudio Brufatto et al., "From Mud to Cement—Building Gas Wells," *Oilfield Review* 15, no. 3 (2003): 62–76.

gas through cracks in their cement casings, likely caused by cement shrinkage over time and exacerbated by upward pressure from natural gas. According to their paper, in Alberta, it is common for wells to leak natural gas into aquifers. "Because of the nature of the mechanism, the problem is unlikely to attenuate," they wrote, "and the concentration of the gases in the shallow aquifers will increase with time."[949]

[949] Maurice B. Dusseault, Malcolm N. Gray, and Pawel A. Nawrocki, "Why Oilwells Leak: Cement Behavior and Long-Term Consequences," *Society of Petroleum Engineers*, 2000, https://www.parliament.vic.gov.au/images/stories/committees/EPC/Submission_903_-_Attachment_A_-_The_Portland_Field_Naturalists_Club.pdf.

Radioactive releases

Radioactive materials, including uranium, polonium, and radon, are commonly found in shale formations. These can be released as airborne contaminants during drilling and fracking operations, as revealed by a 2020 study that documented the presence of airborne radioactive particles downwind from fracking sites at levels sufficient to raise health risks for nearby residents. Radioactive materials are also often components of liquid and solid fracking waste, including sludge and drilling cuttings. These raising exposure risks for workers and the general public. Exemptions from federal hazardous waste laws mean that no national regulatory framework exists for handling the disposal of radioactive materials from oil and gas extraction activities. Instead, regulation is the responsibility of individual states, which vary widely in their approaches.

High levels of radiation documented in fracking wastewater from many shale formations imperil groundwater and surface water. Measurements of radium in fracking wastewater in New York and Pennsylvania, from the particularly radioactive Marcellus Shale, have been as high as 3,600 times the regulatory limit for drinking water, as established by the U.S. Environmental Protection Agency (EPA). Studies have found toxic levels of radiation in Pennsylvania waterways even after fracking wastewater was disposed of through an industrial wastewater treatment plant. In 2020, New York State banned the practice of dumping out-of-state fracking waste in municipal landfills. A 2021 investigation found that a fracking waste disposal site in Texas has been importing radioactive oilfield waste from abroad.

Increasing evidence documents illegal, haphazard dumping of radioactive fracking waste, along with its disposal in municipal landfills not engineered to contain radioactivity. Drill cuttings—the pulverized rock pulled up during the drilling process—are a special concern as this form of solid waste, generated in prodigious amounts, is typically disposed of in municipal landfills lacking special protections for hazardous waste. Radioactivity in drill cuttings has been shown to exceed, in some cases, the regulatory limits for landfills that accept fracking waste. In some states, drill cuttings are repurposed as road-building materials.

As confirmed in a 2023 study, the scaly mineral build-up that accumulates inside fracking equipment can also be a significant source of radiation because radium coprecipitates within calcium carbonate and barium sulfate.

Research suggests that the chemical composition of fracking fluid itself helps to mobilize radioactive materials in the shale.

Studies have found high levels of radon in buildings located in heavily drilled areas of both Pennsylvania and Ohio, with levels of radon rising since the start of the fracking boom, although not all studies show consistent results. Unsafe levels of radon and its decay products in natural gas produced from the Marcellus Shale may also contaminate pipelines and compressor stations, as well as pose risks to end-users when allowed to travel into homes.

- June 1, 2023 – A study of radioactive fracking waste compared two different unpermitted landfills—one in Kentucky and one in Oregon—that had received such waste. Geological and hydrological characteristics varied between sites as did the type of radioactive materials deposited: more brine in Kentucky and more solid radioactive waste at the Oregon site. The materials accepted as waste also differed as did the used of liners and personal protective equipment for workers. Risk assessments compared three scenarios for current and future receptors: during disposal, a closure-in-place alternative, and an excavation alternative. The exposure pathway for potential receptors depended on method of removal, and included inhalation of radon or suspended particles blown offsite during removal operations, inadvertent soil ingestion, and external exposure. In both risk assessments, the preferred remediation alternative was to leave the materials in place as it was far more protective of on-site workers, the public, and the environment. Further, the authors advocated for a uniform Federal standard for disposal of naturally occurring radioactive materials whose radionuclide concentrations have been increased by human activity. [Note that the authors of this study were all employed by limited liability corporations that engage in environmental risk assessments.][950]

- February 25, 2023 – In Brazil, no repositories exist for the storage of radioactive wastes from oil and gas extraction activities. Instead, they are stored in drums at sites not intended for radioactive materials. A radiological assessment of oil and gas industry waste in Brazil asked whether the effective doses at these local facilities remain below the annual limit for public exposure. Using methods developed by the Argonne National Laboratory for the United States Department of Energy and the United States Nuclear Regulatory Commission, the research team evaluated the radiological dose and excess cancer risk for individuals exposed while within or outside the area of primary contamination. Several pathways of exposure were considered, and the scenario selected was a subsistence farm with crops and animals raised on top of the closed landfill with residents drinking water from a well located next to the site. The results showed that one factor mediating risk was the depth of soil covering the waste, with greater cover being more protective. "The main exposure pathway contributing the total effective dose and the cancer risk in all scenarios analyzed was direct radon exposure from the primary contamination and from atmospheric release."[951]

- February 9, 2023 – Particularly high concentrations of radioactivity are found on oil and gas extraction equipment where scaly mineral build-up accumulates, especially barium sulfate and calcium carbonate, within which radium coprecipitates. The pathway of exposure is via inhalation. For this study, researchers analyzed five samples of scale collected from oil and gas equipment in southern Algeria for the presence of radioactive isotopes (radium, thorium, and potassium) The findings indicated that gonadal doses of radioactivity were excessive. "All mean hazard parameters are greater than the

[950] Emily A. Caffrey et al., "Comparison of Doses from Disposals of Technologically Enhanced Naturally Occurring Radioactive Materials in Kentucky and Oregon," *Health Physics* 124, no. 6 (June 2023): 441–50, https://doi.org/10.1097/HP.0000000000001683.
[951] Amanda Gomes Lopes, Francisco Cesar Augusto Da Silva, and Ricardo Tadeu Lopes, "Radiological Assessment of the Disposal of Bulk Oil NORM Waste: Case Study from Brazil," *Journal of Environmental Radioactivity* 261 (May 2023): 107139, https://doi.org/10.1016/j.jenvrad.2023.107139.

recommended safety limit, and the estimated dose rates show that long-term accumulation of [radioactive] scale residues may lead to possible radiological hazards in the future." The authors recommend special methods during cleaning and maintenance, such as chemically treating scale residues, storing residues in underground bunkers, and reducing personal exposure and environmental contamination through regulatory controls.[952]

- October 3, 2022 – The Radiation Protection Bureau of Health Canada reviewed industrial activities, outside of the nuclear industry, that involve naturally occurring radioactive materials to clarify the variety of regulations governing different industries and consolidate that information into one source. The report identifies oil and gas extraction, as the industry with the largest number of exposed workers. Further, the oil and gas sector is the industry responsible for the largest air and land releases of radioactive materials and the second largest source of radioactive materials released to water. (Metal ore mining was number one.)[953]

- June 1, 2022 – A research team analyzed shale gas wastewater from several sites in the Sichuan Basin in China to determine the potential for recovering and monetizing valuable chemicals including salts, strontium, lithium, and gallium. The findings showed that current technology does not provide an economically feasible way to extract them. Further, while radioactivity was 95 percent removed, the radioactive residuals left behind still exceeded drinking water standards. Noting that residual radioactivity persisted in shale gas wastewater pretreated with sophisticated disc tube reverse osmosis, the authors raised concerns about levels of radioactivity in wastewater not treated with reverse osmosis.[954]

- June 1, 2021 – A longstanding target of public opposition, the Keystone Sanitary Landfill, near Scranton, Pennsylvania accepts radioactive fracking waste and is seeking approval for a major expansion across 435 acres. An investigative report found that this facility has contaminated groundwater, dumped illegally, and is under federal investigation and litigation. Of particular concern are the open piles of radioactive materials that continue to accumulate in this facility. In response, the Pennsylvania Attorney General opened an investigation into Keystone regarding an alleged leachate dumping incident in September 2016 with a specific focus on the "harmful effects on the

[952] El Hadji Mamadou Fall et al., "Assessment of Occupational Radiation Exposure of NORM Scales Residues from Oil and Gas Production," *Nuclear Engineering and Technology* 55, no. 5 (May 2023): 1757–62, https://doi.org/10.1016/j.net.2023.02.012.
[953] Jing Chen, "A Review of Current Inventory for Major Industries Involving Naturally Occurring Radioactive Materials in Canada," *Journal of Radiological Protection* 42, no. 3 (September 1, 2022): 031520, https://doi.org/10.1088/1361-6498/ac9396.
[954] Wancen Xie et al., "Shale Gas Wastewater Characterization: Comprehensive Detection, Evaluation of Valuable Metals, and Environmental Risks of Heavy Metals and Radionuclides," *Water Research* 220 (July 2022): 118703, https://doi.org/10.1016/j.watres.2022.118703.

air quality, safety, and health of the citizens of Scranton, as well as the water quality of Meadow Brook Creek and the Lackawanna River."[955]

- April 26, 2021 – Solid waste from oil-based drilling operations contains carcinogenic contaminants, including heavy metals and polycyclic aromatic hydrocarbons, as well as radionuclides. A research team assessed the chemical composition and radioactive strength in samples of this waste, in order to estimate the public health risks from exposure to these wastes when incorporated into roadbed materials. This risk assessment evaluated several pathways of exposure—ingestion, respiration, and via groundwater—and found that repurposing drill cuttings for roadbed materials poses unacceptable levels of risk.[956]

- April 22, 2021 – A year-long independent investigation documented that a large West Texas oil and disposal facility, Lotus LLC, already cited for not following its disposal protocol, has been importing radioactive oilfield waste from abroad. Classified as non-hazardous under the Bevill and Bentsen Amendments, oil and gas waste is often highly radioactive. Indeed, Lotus LLC received a drum of waste from Australia, transported on a cargo jet, containing levels of radium that exceeded EPA limits for Superfund sites and uranium mills by a factor of 400. The investigation found, through aerial photos and interviews, multiple instances of radioactive material stockpiled in "damaged, rusted, and degraded tanks or barrels stored directly on an unlined surface without proper containment to prevent leaching, runoff, and other direct risks to groundwater and surface contamination." Open tanks had large quantities of "filter socks" and pipe scale from drilling sites. Both are known to be typically highly radioactive. The state's Railroad Commission found no violations in its most recent inspection and had no comment on the photos or independent investigation. No specific permits are required to import radioactive oil and gas waste.[957]

- March 30, 2021 – Radon is a proven cause of lung cancer, and shale basins where fracking occurs typically have high radon concentrations due to the decay of naturally occurring uranium. In this study, the authors identified radon hotspots throughout the state of Pennsylvania, looked at radon trends from 1988 through 2018, and asked whether fracking activities—by breaking up rocks and allowing great flow of radon gas into soil—have increased radon levels inside residential homes. They also examined how factors such as seasonal changes in weather might influence indoor radon concentrations. The aim was to offer mitigation measures and thereby reduce lung cancer risk. The results showed that geology is the primary factor affecting radon levels in Pennsylvania,

[955] Emma Lichtwardt and Joshua Boaz Pribanic, "America Is Building Mountains of Radioactive Fracking Waste & the One in Joe Biden's Hometown Is Under Criminal Investigation" (Public Herald, June 2021), https://publicherald.org/america-is-building-mountains-of-radioactive-fracking-waste-the-one-in-joe-bidens-hometown-is-under-criminal-investigation/.
[956] Deming Xiong and Chaoqiang Wang, "Risk Assessment of Human Exposure to Heavy Metals, Polycyclic Aromatic Hydrocarbons, and Radionuclides in Oil-Based Drilling Cutting Residues Used for Roadbed Materials in Chongqing, China," *Environmental Science and Pollution Research*, 2021, https://doi.org/10.1007/s11356-021-13871-0.
[957] Justin Nobel, "Where Does All The Radioactive Fracking Waste Go?," DeSmog International, April 22, 2021, https://www.desmog.com/2021/04/22/lotus-llc-radioactive-fracking-waste-disposal-texas/.

with shales, limestone, and granite all containing elevated levels of radon. Single family homes, tested at the basement level, in Northeast Pennsylvania had the highest radon concentrations. Higher levels were found in the winter, possibly due to less ventilation. Homes in rural areas where most fracking occurs, showed significant variability. More research is needed to make solid recommendations regarding mitigation.[958]

- March 1, 2021 – In September 2020, Roulette Oil & Gas applied for an EPA permit to convert one of their conventional wells in Potter County, Pennsylvania into a Class II-D injection well to dispose of liquid waste from 110 conventional oil and gas wells in the area and possibly three fracked wells. Only 10 Class II-D permits have ever been issued for all of Pennsylvania. Local officials were not notified of the application, arousing suspicion that the secrecy was intentional. An investigative news report revealed that the permit application did not state that oil and gas waste would contain radioactive material and that the federal permit itself, if received, would only require chemical testing every two years and would not require testing for radioactive materials. Radiation testing would be left to the state of Pennsylvania, which has not created such regulations for oil and gas wastewater injection wells."[959]

- February 18, 2021 – Two workers suffered burns in an eruption and blaze fueled by oil and gas waste materials at a truck stop cleaning station in West Virginia, prompting community and workers to raise concern about such facilities accepting and processing oil and gas waste, including radioactive waste, within Marcellus and Utica shale regions. As determined by the West Virginia Department of Environmental Protection, this particular blaze was likely ignited by a torpedo space heater when it came into contact with oil and gas vapors wafting from the fracking flowback waste and brine waste in a truck. Both materials were being processed by the facility at the time.[960]

- December 14, 2020 – Two oil and gas industry professionals described shocking experiences of radiation exposure to themselves and others, in an investigative report that referred to fracking workers in Appalachia's Marcellus Shale region as "the industry's black box." The investigation, which interviewed gas and oil industry whistleblowers, reported that workers in Ohio and Pennsylvania are exposed to radioactive materials through various tasks which bring them into direct contact with drill cuttings from fracking bores that have cut through radioactive shale, and with scales and sludges formed on piping and in tank bottoms. According to a radiation control consultant interviewed in the investigation, these materials can be, "much hotter than most stuff in nuclear plants." Radiation monitors are not typically found on site. One of the industry professionals, a hazardous materials technician for several of the largest companies

[958] Kyle R. Kellenbenz and Kabindra M. Shakya, "Spatial and Temporal Variations in Indoor Radon Concentrations in Pennsylvania, USA from 1988 to 2018," *Journal of Environmental Radioactivity* 233 (July 2021): 106594, https://doi.org/10.1016/j.jenvrad.2021.106594.
[959] Sam Sanson, "Stopping Radioactive Water: Officials Want to Ban Oil & Gas Injection Wells at Pennsylvania Headwaters," March 2021, https://publicherald.org/stopping-radioactive-water-officials-want-to-ban-oil-gas-injection-wells-at-pennsylvania-headwaters-to-block-epa-permit/.
[960] Justin Nobel, "Fire at Oil and Gas Waste Site Raises Safety Concerns Around Possible Radioactive Accidents," DeSmog International, February 18, 2021, https://www.desmog.com/2021/02/18/fire-oil-gas-waste-petta-dallas-pike-safety-radioactivity/.

regionally, described the challenge of workers trying to control their own risk when they did not have information on the hazard, as when he and co-workers decided to take their own gamma scanners onto cleanup project sites. With no training from the clients who hired them, he described a, "deliberate failure to disclose." A second professional, who trained as a nuclear health physicist in the U.S. Navy and started his own company to help the industry with radiation safety, described his encounters with "incredibly unsafe" situations for workers and their families. After finding one pipeyard with "particularly egregious" concentrations of radium-226, his company visited the employees' homes, and found "incredibly hot" laundry, as well as highly contaminated, bedding, clothing, and carpets, with two small children interacting with these materials as he took measurements. He described industry resistance to even simple interventions that companies could use to reduce risks to workers and their families.[961]

- October 13, 2020 – A Harvard team documented the presence of airborne radioactivity downwind from fracking sites at levels sufficient to raise health risks for nearby residents. Using data collected from 157 radiation-monitoring stations built across the nation during the Cold War, the researchers showed a seven percent increase in radioactive pollution in communities located 12 to 31 miles downwind from operational fracking sites as compared to background levels. The closer communities were located to the wells, the higher the radioactivity in airborne particles. In the Fort Worth, Texas area, where more than 600 fracking wells are located upwind from the city, the team estimated a 40 percent increase in radiation levels. The radioactive elements carried by the ultrafine particles, including polonium, represent the radioactive decay products of uranium isotopes that are liberated from the shale during fracking operations.[962]

- September 7, 2020 – With growing public concern about more than two dozen cases of rare Ewing's sarcoma among teens and young adults in intensely fracked areas of southwestern Pennsylvania, investigative reporters at *Public Herald* pressed the Pennsylvania Department of Health (DOH) for more information about the scope and progress of the public health studies that were promised to local residents. DOH has relinquished the study format to the University of Pittsburgh, and there is no indication that the research team is planning to investigate the issue of fracking-related radioactivity despite the concern of many residents that such exposures may be playing a role in the unusually high incidence of an otherwise rare cancer.[963]

- August 5, 2020 – Using state records and right-to-know-law requests, an investigative team at the *Public Herald* found that final destination of 66 percent of the leachate from 30 different landfills in Pennsylvania that accept oil and gas waste from fracking operations is unknown. Further, the leachate is not being tested for radioactivity before

[961] Kristen Locy and Justin Nobel, "Oil & Gas Whistleblowers Speak Out About Exposure to Radioactivity on Fracking Jobs" (Public Herald, December 2020), https://publicherald.org/if-only-i-wouldve-known-oil-gas-whistleblowers-speak-out-about-exposure-to-radioactivity-on-fracking-jobs/.
[962] Longxiang Li et al., "Unconventional Oil and Gas Development and Ambient Particle Radioactivity," *Nature Communications* 11 (2020), https://doi.org/10.1038/s41467-020-18226-w.
[963] Kristen Locy and Joshua Pribanic, "DOH Continues to Dodge Health Impacts from Oil & Gas Radiation, Passes Study to the University of Pittsburgh" (Public Herald, September 2021), https://publicherald.org/doh-continues-to-dodge-health-impacts-from-oil-gas-radiation-passes-their-health-study-to-the-university-of-pittsburgh/.

being discharged into rivers and streams. Leachate is a landfill's liquid waste formed by rainwater percolating through the landfill. It is typically sent to wastewater treatment plants before being discharged into surface water. Oil and gas waste from Marcellus Shale fracking operations that are dumped in landfills can contain high levels of Technically Enhanced Naturally Occurring Radioactive Materials (TENORMS), meaning that naturally occurring radioactivity within the earth's geological layers is mobilized and concentrated by the activities of fracking when it is brought to the surface as a constituent of liquid and solid waste. TENORMS are not removeable by the filtration systems of most treatment plants. Pennsylvania state records show radium-226 levels in fracking wastewater can be as high as 26,000 picocuries per liter, which is more than 5,000 times the limit for radium in drinking water. The team found that the Pennsylvania Department of Environmental Protection (DEP) is limiting the amount of TENORM coming into its landfills by limiting the amount of waste the landfill can receive. However, the agency is not tracking the amount of TENORM leaving the landfill and heading to water treatment facilities in the form of leachate. "The DEP says that the transaction is private between the two entities: the landfill and the treatment plant."[964] New state legislation was drafted in 2019 that would prevent TENORM disposal in Pennsylvania public waters.[965]

- August 3, 2020 – Oil and natural gas waste became subject to state law regulating the transportation, treatment, storage and disposal of hazardous waste, as New York State Governor Andrew Cuomo signed into law S3392/A2655.[966] Though the state had banned extraction of natural gas by fracking in 2015, fracking waste arrives into the state from Pennsylvania and was previously treated as non-hazardous, in spite of the carcinogenic compounds and naturally occurring radioactive materials it contains.[967]

- July 18, 2020 – Exposure to radionuclides from oil and gas waste was greater when waste was in bulk rather than containerized, and greater exposure occurred with smaller vehicles for transport, according to researchers from the Department of Civil Engineering-University of Indonesia and the Indonesian Nuclear Energy Regulatory Agency.[968] The team evaluated exposure to radionuclides from oil and gas waste by landfill worker job description: drivers, workers receiving the waste, and workers

[964] Joshua Pribanic and Talia Wiener, "Pennsylvania Regulators Won't Say Where 66% of Landfill Leachate w/ Radioactive Material From Fracking Is Going…'It's Private'," *Public Herald*, August 5, 2020, https://publicherald.org/pennsylvania-regulators-wont-say-where-66-of-landfill-leachate-w-radioactive-material-from-fracking-is-going-its-private/.
[965] Joshua B. Pribanic, "'Government Failed You' - Pittsburgh State Rep. Drafts Bill to Stop Radioactive Fracking Waste (TENORM) From Entering Public Waters," *Public Herald*, December 10, 2019, https://publicherald.org/government-failed-you-pittsburgh-state-rep-drafts-bill-to-stop-radioactive-fracking-waste-tenorm-from-entering-public-waters/.
[966] "Cuomo Signs Legislation Regulating Oil- and Gas-Related Waste," *Niagara Frontier Publication*, August 3, 2020, https://www.wnypapers.com/news/article/current/2020/08/03/142660/cuomo-signs-legislation-regulating-oil-and-gas-related-waste.
[967] Rachel May, "Legislature Closes Decade Long Loophole on Treatment of Hazardous Fracking Waste," Press Release (New York State Senate, July 22, 2020), https://www.nysenate.gov/newsroom/press-releases/rachel-may/legislature-closes-decade-long-loophole-treatment-hazardous.
[968] C. A. W. Dwipayana, S. S. Moersidik, and M. A. Pratama, "Estimation Radiation Dose From Operation of Petroleum NORM Waste Disposal in Landfill Using TSD-DOSE," *Journal of Physics: Conference Series, 1572* 1572 (2020), https://doi.org/10.1088/1742-6596/1572/1/012031.

disposing of the waste. The method used was that of the US Department of Energy to evaluate radiation exposure at Transport, Storage and Disposal (TSD) facilities.

- April 22, 2020 – The National Council of Radiation Protection and Measurements (NCRP), which is chartered under, but not overseen by, the U.S. Congress, called for the development of a full report to provide science-based national guidelines for the disposal radioactive waste from fracking operations. In its commentary, the NCRP described the geological origins of radioactivity in oil and gas drilling; the historical and current regulatory framework; options for the disposal of radioactive waste; legal considerations; and radiation protection measures for workers. The NCRP further notes that the EPA does have the authority to regulate individual radionuclides under a suite of federal environmental laws. However, because EPA has not thus far provided any regulations or even guidance, regulatory action has, heretofore, fallen to the states with little input from federal advisory bodies. In the absence of consistent, standard regulations across the states—and in some states there are none at all—compliance difficulties arise.[969]

- February 13, 2020 – In violation of Oregon state regulations, two million pounds of radioactive fracking waste from North Dakota Bakken's oil field was received by a chemical waste landfill near Oregon's Columbia Gorge, delivered by rail in 2016, 2017 and 2019. Some of the waste "registered radium at 300 times the state's limits," and on average, "registered radium at 140 picocuries per gram," while the state maximum for the facility is five picocuries, according to a state nuclear waste remediation specialist quoted in *Oregon Live*.[970] Citing lack of malicious intent, authorities will not fine the landfill, but require the company to create a risk assessment and action plan to address the violation.

- January 21, 2020 – *Rolling Stone* reporter Justin Nobel investigated radioactive materials in fracking waste, including fracking waste dumped in landfills and through sewage treatment plants, liquid fracking waste spread on roadways, and wastewater hauled to underground injection wells for disposal. Truckers are not required to wear protective gear or wear dosimeters to measure exposure, and they frequently become soaked in the wastewater they are disposing. Involving hundreds of interviews, *Rolling Stone's* investigation uncovered "a sweeping arc of contamination—oil-and-gas waste spilled, spread, and dumped across America, posing under-studied risks…. There is little public awareness of this enormous waste stream, the disposal of which could present dangers at every step—from being transported along America's highways in unmarked trucks; handled by workers who are often misinformed and under protected; leaked into waterways; and stored in dumps that are not equipped to contain the toxicity. Brine has even been used in commercial products sold at hardware stores and is spread on local roads as a de-icer." A set of recently settled lawsuits among Louisiana oil and gas

[969] NCRP Scientific Committee 5-2, "Naturally Occurring Radioactive Material (NORM) and Technologically Enhanced NORM (TENORM) from the Oil and Gas Industry," NCRP Commentary (National Council on Radiation Protection and Measurements, 2020), https://ncrponline.org/shop/commentaries/commentary-no-29/.
[970] Laura Gunderson, "Oregon Landfill Accepted 1 Million Pounds of Radioactive Fracking Waste From North Dakota," *The Oregonian*, February 13, 2020, sec. Environment, https://www.oregonlive.com/environment/2020/02/oregon-landfill-accepted-2-million-pounds-of-radioactive-fracking-waste-from-north-dakota.html.

workers revealed chronic exposures that led to fatal cancers. Historical industry documents expose long-standing inhouse concerns about liability for oil and gas workers' health from radiation exposures.[971]

- December 23, 2019 – In a study of radioactivity within the Polish gas pipeline network, excess radon, or ^{222}Rn, concentrations were found in gas from national mines compared to gas from international sources, due to transit time and radon's short half-life. Very high radiolead, or ^{210}Pb, was found in "black powder" samples. Black powder is a product of corrosion of steel pipes and is found in filters at compressor stations and from pigging operations. Faculty researchers from the University of Science and Technology in Krakow, Poland concluded that handling black powder presents radiological risk to employees.[972]

- November 29, 2019 – Exposure to TENORM waste from the oil and gas industry "may lead to multiple environmental and health risks," according to a review analyzing and comparing available international data from extraction, production and transport.[973] The American Petroleum Institute reported that scales in the oil and gas industry, often found inside pipes and tubes at fracking sites, had concentrations as high as tens of thousands of Bq g^{-1}; it can also contain radon offspring, such as ^{210}Pb and ^{210}Po. In addition, some studies found excess radioactivity in soil in the vicinity of oil and gas industry fields and facilities. Based on their review of many studies, the authors concluded that oil and gas activities exceed the 10,000 Bq kg^{-1} exemption level recommended in the safety standards of the International Atomic Energy Agency (IAEA). In particular, they wrote that TENORM waste produces high levels of radiation exposure because radioactivity often accumulates on machinery and equipment, due to mismanagement, physical conditions, and other factors.

- September 25, 2019 – Radioactive materials in oil and gas industry waste represent an unknown risk for workers and community members. An Egyptian research team investigated the potential health effects of low-levels exposure to these substances in laboratory rats. Waste exposure for one and two months resulted in a significantly increased production of cellular free radicals, elevations in lipid peroxides, and damage to red blood cells.[974] Exposure also triggered a radio-adaptive response in rats subsequently exposed to a higher dose of gamma radiation, particularly in the longer-exposed animals.

- September 11, 2019 – A Pennsylvania municipal worker observed irregularities in sewage releases that led to the discovery that 40 percent of waste in a local landfill was, in fact, solid oil and gas waste, including drill cuttings. The superintendent of the Belle

[971] Justin Nobel, "America's Radioactive Secret," *Rolling Stone*, January 21, 2020, sec. Politics, https://www.rollingstone.com/politics/politics-features/oil-gas-fracking-radioactive-investigation-937389/.
[972] Jakub Nowak, Pawel Jodlowski, and Jan Macuda, "Radioactivity of the Gas Pipeline Network in Poland," *Journal of Environmental Radioactivity* 213 (2020): 106143, https://doi.org/10.1016/j.jenvrad.2019.106143.
[973] Mohsen M. M. Ali et al., "Concentrations of TENORMs in the Petroleum Industry and Their Environmental and Health Effects," *RSC Advances* 9, no. 67 (2019): 39201–29, https://doi.org/10.1039/c9ra06086c.
[974] Seham M. El-Marakby et al., "Assessment of Chronic Exposure Effects and Radioadaptive Response of Natural Occurring Radioactive Materials (NORM)," *Radiation Physics and Chemistry* 166 (2020): 108502, https://doi.org/10.1016/j.radphyschem.2019.108502.

Vernon Municipal Authority, which runs the town's small sewage treatment plant on the banks of the Monongahela River, found barium, chlorides, and, of particular concern, radium, in the leachate from the landfill at levels higher than allowed by EPA's drinking water standards. A *State Impact Pennsylvania* investigation found that this sewage treatment plant, along with 12 others, were "too small to automatically qualify for stricter regulations on leachate, and have to police the landfills themselves." Duke University geochemist Avner Vengosh cautioned, "I predict that the radium will start to accumulate on the sediments at the bottom of this discharge site…The radioactivity level could be really high. And of course the risk is that once there is high radium in the sediments, there is incorporation into the ecological chain."[975]

- April 10, 2019 – In a study of 118,421 homes in all 88 Ohio counties, a University of Toledo team used multilevel modeling to investigate the relationship of indoor radon concentrations and fracked well locations for the years 2007-2014. The found that proximity of Ohio homes to fracking wells was linked to higher indoor concentrations of radon gas.[976] "The shorter the distance a home is from a fracking well, the higher the radon concentration. The larger the distance, the lower the radon concentration," according to lead researcher, Ashok Kumar.[977] Most of the gas wells were located in eastern Ohio which overlies the shale deposits. The mean radon concentrations among the tested homes was 5.76 pCi/l, which is higher than the EPA's "safe" levels of 4.0 pCi/l. (The World Health Organization recommends mitigation at 2.7 pCi/l.) The highest radon concentration, 141.85 pCi/l, was found in central Ohio. The data in the study were collected from self-reported devices. Researchers concluded, "there is a strong correlation between indoor radon concentrations and hydraulic fracturing in Ohio."

- March 15, 2019 – Due to a 1980 hazardous waste exemption from the Resource Conservation and Recovery Act (RCRA), drill cuttings from oil and gas fields became exempt from federal oversight, leaving it to states to regulate the disposal of this solid waste stream. A team of researchers measured radioactivity in drill cuttings extracted from Pennsylvania wells and found levels of radium-226 and radium-228 that exceeded the regulatory limits for landfills in Ohio and New York, two states where there are regulatory limits and that accept fracking waste from other states, including from Pennsylvania. The authors recommended rescinding the RCRA exemption for hazardous fracking waste to better protect public health.[978]

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[975] Reid Frazier, "How Did Fracking Contaminants End up in the Monongahela River? A Loophole in the Law Might Be to Blame," *State Impact Pennsylvania*, September 11, 2019, https://stateimpact.npr.org/pennsylvania/2019/09/11/how-did-fracking-contaminants-end-up-in-the-monongahela-river-a-loophole-in-the-law-might-be-to-blame/.

[976] Yanqing Xu, Mounika Sajja, and Ashok Kumar, "Impact of the Hydraulic Fracturing on Indoor Radon Concentrations in Ohio: A Multilevel Modeling Approach," *Frontiers in Public Health* 7, no. 76 (2019), https://doi.org/10.3389/fpubh.2019.00076.

[977] University of Toledo, "Fracking Linked to Higher Radon Levels in Ohio Homes," *Science Daily*, June 18, 2019, https://www.sciencedaily.com/releases/2019/06/190618083347.htm.

[978] Elaine W. Swiedler et al., "Should Solid Waste From Shale Gas Development Be Regulated as Hazardous Waste?," *Energy Policy* 129 (2019): 1020–33, https://doi.org/10.1016/j.enpol.2019.02.016.

- August 3, 2018 – A two-part study by Dartmouth College researchers investigated the source of radium in fracking wastewater from Marcellus Shale wells. By comparing the isotopic ratios, they showed that the high salinity of the wastewater is responsible for extracting radium from the shale. "Experimental results and wastewater data together provide a coherent picture, that the distinctive Ra isotopic signature of Marcellus wastewaters results from contemporaneous water-rock interactions that promote desorption of ^{226}Ra from organics during hydraulic fracturing."[979] In the second part of the study, the researchers used mass balance and isotope mixing models to attribute both the extreme salinity and the presence of radium in liquid fracking waste to the progressive, hydrologic enrichment of injected fluids during hydraulic fracturing.[980] In sum, the chemical composition of fracking fluid itself and its interactions with black shale during the fracking process combine to make fracking waste radioactive. Explaining these findings in a news article, co-author Makul Sharam said, "Radium is sitting on mineral and organic surfaces within the fracking site waiting to be dislodged. When water with the right salinity comes by, it takes it on the radioactivity and transports it."[981]

- February 19, 2018 – A study conducted in the Bakken Shale region of North Dakota used a multivariate regression model to predict radium-226 levels in fracking wastewater based on levels of other elements (barium, strontium, calcium). Their simulation model gave results that align with the extremely limited actual data based on direct measurements of radionuclides in Bakken Shale wastewater. The research team then used their model to predict potential harm to human health based on spills into surface water that is issued as a source of drinking water, irrigation, and recreational fishing. Even in the best-case scenario, using simulated concentrations on the low end, the results indicated that "there is potential risk to human health" in North Dakota due to radium-226 in fracking wastewater spills. This model can be used for any area where oil and gas waste is produced. "Overall, the results presented in this study can be treated as a warning and a reference to conduct further investigations."[982]

- February 6, 2018 – A research team from City University of New York School of Public Health and Health Policy surveyed the various state-based regulations and state licensing requirements governing the disposal of radioactive waste from oil and gas waste streams. They found that 17 states had drafted express regulations to reduce exposure to radiation from oil and gas waste. States with active oil and gas drilling that lack such regulations "may leave the public and workers susceptible to adverse health effects from radiation."

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[979] Joshua D. Landis et al., "Rapid Desorption of Radium Isotopes From Black Shale During Hydraulic Fracturing. 1. Source Phases That Control the Release of Ra from Marcellus Shale," *Chemical Geology* 496 (2018): 1–13, https://doi.org/10.1016/j.chemgeo.2018.06.013.
[980] Joshua D. Landis, Mukum Sharma, and Devon Renock, "Rapid Desorption of Radium Isotopes From Black Shale During Hydraulic Fracturing. 2. A Model Reconciling Radium Extraction With Marcellus Wastewater Production," *Chemical Geology* 500 (2018): 194–206, https://doi.org/10.1016/j.chemgeo.2018.08.001.
[981] Dartmouth College, "How Slick Water and Black Shale in Fracking Combine to Produce Radioactive Waste," *Science Daily*, September 18, 2018, https://www.sciencedaily.com/releases/2018/09/180918154831.htm.
[982] L. Torres, O. P. Yadav, and E. Khan, "Risk Assessment of Human Exposure to Ra-226 in Oil Produced Water From the Bakken Shale," *Science of the Total Environment* 626 (2018): 867–74, https://doi.org/10.1016/j.scitotenv.2018.01.171.

Among the authors' policy recommendations: due to accumulation of radioactivity on equipment, future studies should explore impacts on workers; exposed workers should wear badges to monitor exposures; worker exposures should be limited by shift changes; regulations across states should be harmonized to prevent cross-state dumping of large amounts of radioactive solid waste and assure protection of the public from the risk of radiation from exposure to oil and gas drilling wastes.[983]

- January 4, 2018 – A research team from Duke and Pennsylvania State universities collected stream sediments upstream and downstream from three disposal sites in Pennsylvania that receive oil and gas wastewater, treat it, and release it into surface water. While the practice of treating and dumping liquid waste from fracking operations into Pennsylvania streams largely ended in 2011, these three facilities continue to treat and release waste from conventional drilling operations. The researchers consistently detected elevated radioactivity in stream sediments in the vicinity of the outfall compared to upstream areas. The ratios of radium isotopes to their decay products showed that some of the radium had accumulated in the sediments in recent years—after discharges of fracking waste had been halted. Hence, radioactivity from conventionally drilled wells is the likely source of the high levels of radium in sediments downstream from these three treatment plants. Consequently, policies that prohibit disposal only of fracking waste fluids "are not adequate in preventing radioactive contamination in sediments at disposal sites." Permission to treat and release any type of oil and gas wastewater via centralized waste treatment facilities "should be reconsidered."[984]

- September 22, 2017 – State health regulators confirmed that unknown quantities of radioactive waste from drilling and fracking operations have been illegally buried in Colorado landfills not permitted to accept it.[985]

- November 23, 2016 – University of Iowa researchers evaluated radioactive materials—uranium, thorium, radium, lead, and polonium isotopes—from drill cutting samples extracted from a single well drilled in northern Pennsylvania. They found complex patterns of vertical stratification. For example, the deep drill cuttings had significantly more uranium (U) than the cuttings removed from shallow portions of the well. Noting that virtually all drill cutting waste from the Marcellus Shale is deposited in landfills, the authors examined the stability of the various radioactive materials by simulating different conditions of landfill leaching. The results suggested some environmental mobility of radionuclides in drill cuttings. In particular, as acidity increased, radionuclide leaching increased, with ^{238}U and ^{234}U being the most leachable radionuclides. The authors concluded, "Although previous studies have suggested that [radioactive materials] in drill

[983] Elizabeth Ann Glass Geltman and Nichole LeClair, "Variance in State Protection from Exposure to NORM and TENORM Wastes Generated During Unconventional Oil and Gas Operations: Where We Are and Where We Need to Go," *New Solutions* 28, no. 2 (2018): 240–61, https://doi.org/10.1177/1048291118755387.
[984] Nancy E. Lauer, Nathaniel R. Warner, and Avner Vengosh, "Sources of Radium Accumulation in Stream Sediments near Disposal Sites in Pennsylvania: Implications for Disposal of Conventional Oil and Gas Wastewater," *Environmental Science & Technology* 52, no. 3 (2018): 955–62, https://doi.org/10.1021/acs.est.7b04952.
[985] Bruce Finley, "Colorado Landfills Are Illegally Burying Low-Level Radioactive Waste From Oil and Gas Industry, Denver Post Learns," *The Denver Post*, September 22, 2017, sec. Environment, https://www.denverpost.com/2017/09/22/colorado-landfills-illegally-burying-radioactive-waste-oil-gas/.

cuttings pose a minimal health risk to the general public when deposited in landfills, our results indicate that Marcellus Shale drill cuttings warrant further radiochemical investigation."[986]

- April 27, 2016 – Duke University researchers who studied oil and gas wastewater ("brine") spills reported that "the water contamination from brine spills is remarkably persistent in the environment, resulting in elevated levels of salts and trace elements that can be preserved in spill sites for at least months to years …." In addition, radioactivity was elevated in soil and sediment sampled at spill sites, indicating that radium had accumulated in the soils of spill-affected areas.[987] The bigger the spill, the higher the soil radioactivity level. Study author Avner Vengosh told *Inside Climate News*, "We found even if you take away the spill water… you still left behind the legacy of radioactivity in the soils," where it can linger for thousands of years.[988]

- March 10, 2016 – Louisville's *Courier-Journal* reported on illegal dumping of radioactive oil and gas drilling wastes in two Kentucky landfills. Landfill operators in Greenup and Estill counties were issued violation notices for failing to "accurately characterize the waste for what it was, allowing what's considered an illegal release of a hazardous material into the environment." The illegal dumping at the Greenup County landfill alone consisted of 369 tons of radioactive drilling waste.[989]

- February 26, 2016 – Radioactive oil and gas waste from fracking operations in Ohio, Pennsylvania, and West Virginia was illegally sent to Estill County, Kentucky's Blue Ridge Landfill. The radioactive level of the material that was buried "was at least 340 times more than the amount that is allowed to be buried at a solid waste landfill," according to WKYT in Lexington. WKYT reported that Estill County leaders would "fight 'tooth and toenail' to get the bottom of how low-level radioactive waste ended up in a county landfill," and do its own testing at the landfill and nearby schools.[990]

- November 23, 2015 – Absence of federal oversight and, in some cases, a total lack of state regulations for handling radioactive oil and gas waste was the topic of a report in *High Country News*, which detailed the regulatory situation in six Western states: Colorado, Idaho, Montana, North Dakota, South Dakota, and Wyoming. North Dakota alone generates an estimated 70 tons a day of radioactive oil and gas waste. "Because the

[986] Eric S. Eitrheim et al., "Disequilibrium of Naturally Occurring Radioactive Materials (NORM) in Drill Cuttings from a Horizontal Drilling Operation," *Environmental Science & Technology Letters* 3, no. 12 (2016): 425–29, https://doi.org/10.1021/acs.estlett.6b00439.
[987] Lauer, Harkness, and Vengosh, "Brine Spills Associated with Unconventional Oil Development in North Dakota."
[988] Z. Hirji, "Persistent Water and Soil Contamination Found at N.D. Wastewater Spills," *Inside Climate News*, April 29, 2016, http://insideclimatenews.org/news/29042016/north-dakota-wastewater-spill-water-soil-contaminiation-radium-selenium-bakken-oil.
[989] James Bruggers, "State Begins Crackdown on Radioactive Waste," *Courier Journal*, March 10, 2016, sec. Tech, http://www.courier-journal.com/story/tech/science/environment/2016/03/08/state-orders-end-hauling-radioactive-waste/81496490/.
[990] WKYT, "Estill County Leaders to Fight 'Tooth and Toenail' Over Radioactive Waste in Landfill," *WKYT*, February 26, 2016, https://www.wkyt.com/content/news/Estill-Co-leaders-to-fight-tooth-and-toenail-over-radioactive-waste-in-landfill-370308981.html.

waste is often too radioactive to be disposed of in landfills, it sometimes gets dumped illegally." Proposed new rules in North Dakota would raise the radioactivity limit for the waste.[991]

- July 8, 2015 – Radium-226 is the dominant radioactive material in flowback water from hydraulically fractured wells in the Marcellus Shale. A Pittsburgh team of researchers studied its fate in three wastewater storage pits in southwestern Pennsylvania over a 2.5-year period of time. They found that radium-226 concentrations increased when flowback water was being reused for additional fracking operations. Also, radium-226 tended to accumulate in the bottom sludge. This sludge could be classified as radioactive solid waste because it exceeded the radium-226 limit for landfill disposal. A risk assessment showed that potential radiation dose equivalent levels around the three fracking waste pits were within the regulatory limit for the general public.[992]

- April 9, 2015 – A Johns Hopkins Bloomberg School of Public Health study found that levels of radon in Pennsylvania homes—a region with some of the highest indoor radon concentrations in the US—have been rising since 2004, around the time the fracking industry arrived in the state.[993] Radon exposure is the second leading cause of lung cancer worldwide, after cigarette smoking.[994] Researchers found that buildings in counties where the most fracking has taken place in the past decade have had significantly higher radon readings compared with those in low-fracking areas, a difference that did not exist before 2004. Use of well water was associated with 21 percent higher indoor radon concentrations than in buildings using public water sources. This study, the first to define and evaluate the predictors of indoor radon concentrations in Pennsylvania, concluded that radon's presence was related to geology, water sources, weather, and natural gas drilling.[995]

- April 2, 2015 – A team of toxicologists, geochemists, and radiation scientists led by the University of Iowa analyzed the contribution of various naturally occurring radioactive materials (NORM) to the total radioactivity of fracking waste fluids, finding evidence of long-lived, environmentally persistent radioactive decay products.[996] "NORM is emerging as a contaminant of concern in hydraulic fracturing/unconventional drilling wastes, yet the extent of the hazard is currently unknown." The study determined that

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[991] Jodi Peterson, "States Lack Rules for Radioactive Drilling Waste Disposal," *High Country News*, 2015, sec. Pollution, http://www.hcn.org/articles/states-lack-rules-for-handling-radioactive-drilling-waste.
[992] Tieyuan Zhang, Richard W. Hammack, and Radisav D. Vidic, "Fate of Radium in Marcellus Shale Flowback Water Impoundments and Assessment of Associated Health Risks," *Environmental Science & Technology* 49, no. 15 (2015): 9347–54, https://doi.org/10.1021/acs.est.5b01393.
[993] Joan A. Casey et al., "Predictors of Indoor Radon Concentrations in Pennsylvania, 1989–2013," *Environmental Health Perspectives* 123, no. 11 (2015): 1130–37, https://doi.org/10.1289/ehp.1409014.
[994] National Cancer Institute, "Radon and Cancer Fact Sheet," December 6, 2011, http://www.cancer.gov/about-cancer/causes-prevention/risk/substances/radon/radon-fact-sheet.
[995] Susan Phillips and Jon Hurdle, "New Study Raises Possible Link Between Gas Drilling and Radon Levels," *State Impact Pennsylvania*, April 9, 2015, http://stateimpact.npr.org/pennsylvania/2015/04/09/new-study-raises-possible-link-between-gas-drilling-and-radon-levels/.
[996] Andrew W. Nelson et al., "Understanding the Radioactive Ingrowth and Decay of Naturally Occurring Radioactive Materials in the Environment: An Analysis of Produced Fluids from the Marcellus Shale," *Environmental Health Perspectives* 123, no. 7 (2015), https://doi.org/10.1289/ehp.1408855.

previous testing and study methods likely underestimate radioactivity by focusing only on radium. The researchers developed a new method to accurately predict the concentrations of uranium, thorium, and radium and their alpha-emitting progeny, polonium and lead, in fracking wastewater. They found that, under certain conditions, radioactivity increased over time, due to ingrowth of alpha-emitting radioactive progeny of long-lived parent radionuclides such as radium. The authors warned that these decay products may potentially contaminate recreational, agricultural, and residential areas, and that a more detailed understanding is needed of how radionuclides accumulate in higher organisms. In an accompanying article in *Environmental Health Perspectives*, James Burch, a University of South Carolina epidemiologist who was not involved in the study, said that fracking activities and wastewater disposal, which often take place in close proximity to where people live and work, raise risks for human exposure. "The technology is vastly outpacing what we know about the health effects."[997]

- May 8, 2014 – A group of leading medical experts and the American Lung Association of the Northeast detailed research and growing concerns about potential health impacts of radon and radium associated with natural gas production and the Marcellus Shale, in particular. High levels of radiation in the Marcellus Shale could pose health threats if high concentrations of radon and its decay products travel with natural gas, a problem compounded by the short distance Marcellus gas could travel in pipelines to people's homes.[998]

- March 23, 2014 – A team led by toxicology researchers at the University of Iowa identified high levels of radioactivity in fracking wastewater as a significant concern and noted that the testing methods used and recommended by state regulators in the Marcellus Shale region can dramatically underestimate the amount of radioactivity—specifically radium—in fracking wastewater.[999] Results obtained using EPA-recommended protocols can be obscured by the presence of other contaminant mixtures. Regarding the use of EPA protocols with fracking wastewater or other highly saline solutions, Duke University geochemist Avner Vengosh noted, "People have to know that this EPA method is not updated."[1000]

- February 2014 – The Marcellus Shale is known to have high uranium and radium content. According to Mark Engle, USGS geochemist, the concentration of radium-226 can exceed 10,000 picocuries/Liter (pCi/L) in the shale. Radium-226 has a half-life of 1,600 years. Radium and other naturally occurring radioactive materials (NORM) can be

[997] Lindsey Konkel, "What's NORMal for Fracking? Estimating Total Radioactivity of Produced Fluids," *Environmental Health Perspectives* 123, no. 7 (2015), http://ehp.niehs.nih.gov/123-a186/.
[998] J. Campbell, "Fracking Critics Keep Pushing for State-Backed Health Study," *Politics on the Hudson* (blog), May 8, 2014, http://polhudson.lohudblogs.com/2014/05/08/fracking-critics-keep-pushing-state-backed-health-study/.
[999] Andrew W. Nelson et al., "Matrix Complications in the Determination of Radium Levels in Hydraulic Fracturing Flowback Water from Marcellus Shale," *Environmental Science & Technology Letters* 1, no. 3 (2014): 204–8, https://doi.org/10.1021/ez5000379.
[1000] Sharon Kelly, "Research Shows Some Test Methods Miss 99 Percent of Radium in Fracking Waste," *DeSmog*, March 23, 2014, http://www.desmogblog.com/2014/03/23/some-testing-methods-can-miss-99-percent-radium-fracking-waste-new-research-reports.

released from shale rock during drilling and fracking and can emerge with flowback and produced waters. It can thus enter the ambient environment and become concentrated in the sludge that results from treatment of flowback water, and in river sediment around water treatment facilities. It can also be found in landfills in which sludge and sediment have been disposed. Some radium can be found in drinking water. Geochemist Avner Vengosh warned, "Once you have a release of fracking fluid into the environment, you end up with a radioactive legacy."[1001]

- October 2, 2013 – A peer-reviewed study of the impacts of drilling wastewater treated and discharged into a creek by a wastewater facility in western Pennsylvania documented radium levels approximately 200 times greater in sediment samples near the discharge location than in sediment samples collected upstream of the plant or elsewhere in western Pennsylvania. "The absolute levels that we found are much higher than what you allow in the U.S. for any place to dump radioactive material," one of the authors told *Bloomberg News.* The pollution occurred despite the fact that the treatment plant removed a substantial amount of the radium from the drilling wastewater before discharging it. The researchers wrote that the accumulation of radium in sludge removed from the wastewater "could pose significant exposure risks if not properly managed."[1002, 1003]

- February 2013 – In an analysis of fracking sludge samples from Pennsylvania, researchers "… confirmed the presence of alpha, beta, and gamma radiation in the soil and water in reserve pits located on agricultural land." Total beta radiation exceeded regulatory guideline values by more than 800 percent, and elevated levels of some of the radioactive constituents remained in a vacated pit that had been drained and leveled. It is imperative, the research team concluded, "that we obtain better knowledge of the quantity of radioactive material and the specific radioisotopes being brought to the earth's surface from these mining processes."[1004]

- July 26, 2012 – Responding to concern about radon in natural gas produced from the Marcellus Shale, the USGS analyzed ten samples of gas collected near the wellheads of three Pennsylvania gas wells. The agency found radon levels ranging from 1-79 picocuries per liter, with an average of 36 and a median of 32. (The highest radon activity reported here would decay to 19.8 pCi/L in approximately a week; by comparison, the EPA's threshold for indoor air remediation is 4 pCi/L.) Asserting they knew of no previous published measurements of radon in natural gas from the Appalachian Basin, which contains the Marcellus Shale, agency scientists concluded that the number of

[1001] Valeria J. Brown, "Radionuclides in Fracking Wastewater: Managing a Toxic Blend," *Environmental Health Perspectives* 122, no. 2 (2014): A50–55, https://doi.org/10.1289/ehp.122-A50.
[1002] Nathaniel R. Warner et al., "Impacts of Shale Gas Wastewater Disposal on Water Quality in Western Pennsylvania," *Environmental Science & Technology* 47, no. 20 (2013): 11849–57, https://doi.org/10.1021/es402165b.
[1003] Jim Jr. Efstathiou, "Radiation in Pennsylvania Creek Seen as Legacy of Fracking," *Bloomberg*, October 2, 2013, http://www.bloomberg.com/news/2013-10-02/radiation-in-pennsylvania-creek-seen-as-legacy-of-frackin.html.
[1004] Alisa L. Rich and Ernest C. Crosby, "Analysis of Reserve Pit Sludge From Unconventional Natural Gas Hydraulic Fracturing and Drilling Operations for the Presence of Technologically Enhanced Naturally Occurring Radioactive Material (TENORM)," *New Solutions* 23, no. 1 (2013): 117–35, https://doi.org/10.2190/NS.23.1.h.

samples "is too small to … yield statistically valid results" and urged "collection and interpretation of additional data."[1005]

- January 11, 2012 – In its review of the New York State Department of Environmental Conservation's (NYS DEC) Supplemental Generic Environmental Impact Statement (SGEIS) on high volume fracturing, the EPA expressed concerns about the diffusion of responsibility for the ultimate disposal of radioactive wastes generated by treatment or pretreatment of drilling wastewater. The EPA also raised concerns about the lack of analysis of radon and other radiation exposure. "Who is responsible for addressing the potential health and safety issues and associated monitoring related to external radiation and the inhalation of radon and its decay products?" the EPA asked. "Such potential concerns need to be addressed."[1006]

- September 7, 2011 – The USGS reported that radium levels in wastewater from oil and gas wells in New York and Pennsylvania, including those in the Marcellus Shale, "have a distinctly higher median … than reported for other formations in the Appalachian Basin, and range to higher values than reported in other basins." The median level of radium found in Marcellus Shale wastewater in New York, 5,490 pCi/L, is almost 1,100 times the maximum contaminant level for drinking water, which is five pCi/L. In other words, if a million gallons of Marcellus Shale wastewater contaminated with the median level of radium found in New York were to spill into a waterway, 1.1 billion gallons of water would be required to dilute the radium to the maximum legal level.[1007] (The EPA's health-based goal for radium in drinking water is zero.) Over time, radium naturally decays into radioactive radon gas. Thus, higher radium levels also suggest that higher levels of radon may also be present in natural gas produced from the Marcellus Shale.

- February 27, 2011 – The *New York Times* reported on the threat to New York's drinking water from Pennsylvania drilling waste due to the presence of chemical contaminants, including high levels of radioactivity. The investigation found that sewage treatment plants were neither testing for nor capable of removing that radioactivity, which was subsequently discharged into waterways that supply drinking water, and that, in some cases, wastewater contained radium levels that were hundreds of times higher than the drinking water standard. Drillers sent some of this waste to New York State for disposal even though, as the article noted, EPA scientists had warned the state about this very problem in a December 2009 letter that advised against sewage treatment plants

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[1005] Elisabeth L. Rowan and T. F. Kraemer, "Radon-222 Content of Natural Gas Samples from Upper and Middle Devonian Sandstone and Shale Reservoirs in Pennsylvania: Preliminary Data," Open-File Report Series (U.S. Geological Survey, 2012), http://pubs.usgs.gov/of/2012/1159/ofr2012-1159.pdf.

[1006] Environmental Protection Agency, "EPA Comments on Revised Draft NYSDEC Revised dSGEIS for Horizontal Drilling and High-Volme Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs," Press Release, January 11, 2012, https://web.archive.org/web/20120624232731/http://www.epa.gov/region2/newsevents/pdf/EPA%20R2%20Comments%20Revised%20dSGEIS%20Enclosure.pdf.

[1007] Elisabeth L. Rowan et al., "Radium Content of Oil- and Gas-Field Produced Waters in the Northern Appalachian Basin (USA): Summary and Discussion of Data," Scientific Investigations Report, September 7, 2011, https://pubs.usgs.gov/sir/2011/5135/pdf/sir2011-5135.pdf.

accepting drilling waste with radium levels 12 or more times as high as the drinking water standard.[1008]

- 2008-2009 – The New York State DEC found that wastewater from 11 of 13 vertical wells drilled in New York's Marcellus Shale in 2008 and 2009 contained radium levels ranging from 400 times to nearly 3,400 times EPA's safe level limit for radium in drinking water. These figures later informed the 2011 study of radium in drilling wastewater conducted by the USGS.[1009]

- January 1993 – NORM contamination in the oil and gas industry is widespread and can occur as radioactive scale, films, and sludges. "Some contamination may be sufficiently severe that maintenance and other personnel may be exposed to hazardous concentrations," according to this 1993 article in the *Journal of Petroleum Technology*.[1010] Uranium, thorium, radium, and associated decay products from the production of oil is typically found in radioactive scale and produced water. Radon and its long-lived decay products more typically contaminate natural gas facilities. Federal agencies in the United States do not regulate oil and gas waste, so it is up to individual states to regulate the serious problem of disposal of radioactive materials and equipment.

[1008] Ian Urbina, "Regulation Lax as Gas Wells' Tainted Water Hits Rivers 347," *The New York Times*, February 26, 2011, sec. Drilling Down, http://www.nytimes.com/2011/02/27/us/27gas.html?pagewanted=all&_r=0.
[1009] New York State Department of Environmental Conservation, "Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program, Well Permit Issuance for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs (5-133, 5-141, 7-60, Appendix 12, Appendis 13, Rep.)," Technical Report, 2011.
[1010] P. R. Gray, "NORM Contamination in the Petroleum Industry," *Journal of Petroleum Technology* 45, no. 1 (1993): 12–16, https://doi.org/10.2118/22880-PA.

Occupational health and safety hazards

Drilling and fracking jobs are among the most dangerous jobs in the nation with a fatality rate at least four times the national average. Irregularities in reporting practices mean that counts of on-the-job fatalities among oil and gas workers are likely underestimated. Contract workers are especially at risk. In 2021, the most recent year for which data are available, 58 oil and gas extraction workers died on the job, up from 44 deaths in 2020. These deaths represent over 60 percent of the fatal work injuries in the mining sector. In a 2020 study of suicide deaths by industry, workers employed in mining, quarrying, and oil and gas extraction had the highest suicide rate. A 2020 study showed that retired oil and gas workers had the highest prevalence of self-reported poor health of all industry categories of retirees.

Occupational hazards in the fracking industry include motor vehicle accidents, head injuries, blunt trauma, burns, inhalation of hydrocarbon vapors, toxic chemical exposures, radiation exposure, heat exhaustion, dehydration, and sleep deprivation. Two-thirds of workers report reported workday shifts of 12 or more hours. An investigation of occupational exposures found high levels of benzene in the urine of well pad workers, especially those in close proximity to flowback fluid coming up from wells following fracturing activities. Exposure to silica dust, which is definitively linked to silicosis and lung cancer, was singled out by the National Institute for Occupational Safety and Health (NIOSH) as a particular threat to workers in fracking operations where silica sand is used. [See also Sand Mining and Processing and Radioactive Releases.] At the same time, research shows that many gas field workers, despite these serious occupational hazards, are uninsured or underinsured and lack access to basic medical care.

In 2018, the first independent investigation of its kind showed that pipeline construction workers die on the job 3.6 times more often than the average U.S. worker. Pipeline worker deaths occur from crushings, fires, and heat exhaustion. The number of miles of U.S. pipelines tripled from 2006 to 2016, and newer pipelines are less safe than older ones. Pipelines built after 2010 suffer higher failure rates than pipelines built at any other time.

- April 25, 2023 – In 2021, the year on which the 32nd edition of the AFL-CIO's "Death on the Job: The Toll of Neglect" reports, the category that includes oil and gas extraction workers ("mining, quarrying, and oil and gas extraction") again had the third highest fatality rate of all industry groupings. This rate was 14.2 deaths per 100,000 workers, up from 10.5 in 2020. Oil and gas extraction workers specifically comprised 61 percent of the on-the-job fatalities (58 of the 95 deaths) in this category. Oil and gas extraction workers suffered fourteen more deaths in 2021 than in 2020. Oil and gas extraction workers, according to this federal categorization system, include oil and gas extraction, drilling oil and gas wells, and support activities for oil and gas operations.[1011]

[1011] AFL-CIO, "Death on the Job: The Toll of Neglect, 32nd Edition," A National and State-by-State Profile of Worker Safety and Health in the United States (AFL-CIO, April 25, 2023), https://aflcio.org/reports/death-job-toll-neglect-2023.

- March 15, 2023 – In this report on working conditions in the oil and gas industry, "The Future of Energy & Work in the United States: The American Oil & Gas Worker Survey," worker safety emerged as a top concern. The report analyzes results of a cross sectional survey of 1,635 oil and gas workers. A section of the report on safety and liability describes the findings. These include that "45 percent of survey respondents believe that their company's safety program was explicitly or implicitly designed to shift liability of an accident onto the worker." Further, more than 25 percent of workers in the survey said they would hesitate to raise safety concerns with management. Thirty-five percent of respondents "indicated that they had been ordered to engage in unsafe working practices that were in direct violation of established safety practices." Seventeen percent said "they had been threatened to have their employment terminated if they did not engage in unsafe working practice." The authors also provide an analysis of raw data from OSHA's "Severe Injury Report" of 2015-2022. They parsed out incidents related to upstream, midstream and downstream oil and gas jobs, finding 2,484 reported severe injuries and 2,031 hospitalizations. "The leading types of injuries included fractures (722), amputations (692), soreness from injury (163), heat, thermal burns (111), and lacerations (94)."[1012]

- October 19, 2022 – On June 28, 2021, a gas explosion killed two workers and injured two others during routine maintenance using an in-line inspection tool ("pigging") at an Atmos Energy Corporation worksite near Farmersville, Texas. The National Transportation Safety Board (NTSB) Pipeline Investigation Report into the explosion found the probable cause to be "a leaking mainline valve that allowed natural gas to enter the launcher where it mixed with air, creating a flammable gas–air mixture that was ignited by an undetermined source." The Board said that Atmos Energy Corporation's procedures and training practices "did not prepare workers to recognize and safely respond to abnormal operating conditions," and that this contributed to the explosion and its severity.[1013]

- June 23, 2022 – Long daily commutes, nonstandard work schedules, less sleep on workdays, and lack of employer policies were linked to risky driving behaviors by oil and gas extraction (OGE) workers, according to a study by National Institute of Occupational Safety and Health (NIOSH) researchers published in the *American Journal of Industrial Medicine*. Because U.S. oil and gas workers have consistently high fatality rates—with motor vehicle crashes being the leading cause of those deaths—researchers sought understanding of the underlying causes. Of the 500 OGE workers studied, nearly two-thirds reported workdays of 12 or more hours and nearly half reported less than seven hours of sleep per workday. About one quarter of those surveyed reported having fallen

[1012] Megan Milliken Biven and Leo Lindner, "The Future of Energy & Work in the United States: The American Oil & Gas Workers Survey" (True Transition, March 2023), https://www.truetransition.org/_files/ugd/0ad80c_069ea867b3f044afba4dae2a1da8d737.pdf?index=true.
[1013] National Transportation Safety Board, "Atmos Energy Corporation Natural Gas–Fueled Explosion During Routine Maintenance," Pipeline Investigation Report, October 19, 2022, https://www.ntsb.gov/investigations/AccidentReports/Reports/PIR2203.pdf.

asleep while driving a work vehicle or feeling extremely drowsy more than once a month while driving at work. Researchers called for policies and programs to address these risk factors.[1014]

- April 28, 2022 – Chemical and physical hazards are the "most dangerous occupational factors" according to a scoping review aiming to identify influences on sexual and reproductive outcomes among women employed worldwide in the oil, gas, and mining (OGM) industry. Though the authors report a scarcity of global research (their review incorporated 15 studies), the studies they identified and analyzed suggest that menstrual cycle disorders may be due to occupational hazards such as exposure to heavy metals, toxic gases, and dust. The researchers cite the importance of this review and the need for continued research, given that the majority of women working in OGM are of childbearing age. They call for high-quality research that addresses "all potential biological, chemical, and environmental health hazards, particularly air and water pollutants, which are often found in OGM industry."[1015]

- April 26, 2022 – In 2020, the year about which the 31st edition of the AFL-CIO's "Death on the Job: The Toll of Neglect" reports, the category that includes oil and gas extraction workers ("mining, quarrying, and oil and gas extraction") had the third highest fatality rate of all industry groupings. This rate was 10.5 deaths per 100,000 workers. Oil and gas extraction workers specifically comprised over 56 percent of the on-the-job fatalities (44 of the 78 deaths) in this category. Oil and gas extraction workers, according to this federal categorization system, include oil and gas extraction, drilling oil and gas wells, and support activities for oil and gas operations.[1016]

- November 14, 2021 – A NIOSH-led scoping review provided summaries of existing research on the health and safety consequences of shift work, fatigue, and sleepiness in the oil and gas extraction (OGE) workforce and outlined unmet research needs. The researchers found that only a minority of the 78 papers located addressed onshore OGE workers, even though 85 percent of U.S. oil and over 96 percent of U.S. natural gas is produced onshore. This detailed call for filling research gaps relating to shift work and fatigue includes: building knowledge on the impacts of fatigue in OGE; exploring interactions between on- and off-the-job risk factors and behaviors; and identifying and evaluating interventions to address fatigue in OGE. They call for improved methodologies in studies and conclude that "research is needed to assess the effects of

[1014] Kyla Hagan-Haynes et al., "On the Road Again: A Cross-sectional Survey Examining Work Schedules, Commuting Time, and Driving-related Outcomes among U.S. Oil and Gas Extraction Workers," *American Journal of Industrial Medicine* 65, no. 9 (September 2022): 749–61, https://doi.org/10.1002/ajim.23405.
[1015] Rina Hariniaina Razafimahefa, Jerico Franciscus Pardosi, and Adem Sav, "Occupational Factors Affecting Women Workers' Sexual and Reproductive Health Outcomes in Oil, Gas, and Mining Industry: A Scoping Review," *Public Health Reviews* 43 (April 28, 2022): 1604653, https://doi.org/10.3389/phrs.2022.1604653.
[1016] AFL-CIO, "Death on the Job: The Toll of Neglect, 31st Edition," A National and State-by-State Profile of Worker Safety and Health in the United States (AFL-CIO, April 26, 2022), https://aflcio.org/reports/death-job-toll-neglect-2022.

shiftwork, unpredictable work schedules, overtime, on-call, and fatigue on the onshore OGE workforce and in other parts of the world."[1017]

- June 23, 2021 – Minnesota state regulators fined Precision Pipeline $25,000, the minimum required by law, in an incident involving the death of an employee who was run over by a forklift while checking a list of materials at the Enbridge Energy Line 3 site in northern Minnesota. Precision Pipeline contested the citation.[1018]

- May 21, 2021 – In its final report on the October 2019 deadly hydrogen sulfide (H_2S) release at the Aghorn Operating Inc. oil and gas site in Odessa, Texas, the U.S. Chemical Safety and Hazard Investigation Board (CSB) identified "six serious safety issues." These were nonuse of personal H_2S detector, nonperformance of "lockout/tagout," confinement of H_2S inside pump house, lack of a safety management program, nonfunctioning H_2S detection and alarm system, and deficient site security. The CSB made nine recommendations, seven to the company and one each to regulators OSHA and the Texas Railroad Commission. The release killed an Aghorn employee and his spouse. (See July 21, 2020 entry.)[1019]

- May 4, 2021 – In 2019, the U.S. Bureau of Labor Statistics category that includes oil and gas extraction workers ("mining, quarrying, and oil and gas extraction") had the second highest fatality rate, 14.6 per 100,000 workers, of any industry category. Oil and gas extraction workers specifically comprised 82 percent of the on-the-job fatalities (104 of the 127 deaths) in this category. Oil and gas extraction workers suffered ten more deaths in 2019 than in 2018, which was greater than each year before that, since 2014. Oil and gas extraction workers, according to this federal categorization system, include oil and gas extraction, drilling oil and gas wells, and support activities for oil and gas operations.[1020]

- April 26, 2021 – Reporting on OSHA's "Top 10" violations for various industries in 2020, *Safety and Health Magazine* reported that out of a total of 258 OSHA violations for the oil and gas extraction, 102 were cited as serious. In addition, the article noted that 2020 was a year of one of the lowest total OSHA inspections on record.[1021]

[1017] Kyla Hagan-Haynes et al., "US Research Needs Related to Fatigue, Sleep, and Working Hours among Oil and Gas Extraction Workers," *American Journal of Industrial Medicine* 65, no. 11 (November 2022): 840–56, https://doi.org/10.1002/ajim.23310.
[1018] Associated Press, "State Cites Oil Pipeline Contractor after Worker's Death in Northern Minnesota," *Twin Cities Pioneer Press*, June 23, 2021, https://www.twincities.com/2021/06/23/state-cites-oil-pipeline-contractor-after-workers-death-in-northern-minnesota/.
[1019] Katherine A. Lemos, "Hydrogen Sulfide Release at Aghorn Operating Waterflood Station" (U.S. Chemical Safety and Hazard Investigation Board, May 2021), https://www.csb.gov/aghorn-operating-waterflood-station-hydrogen-sulfide-release-/.
[1020] AFL-CIO, "Death on the Job: The Toll of Neglect, 30th Edition," A National and State-by-State Profile of Worker Safety and Health in the United States (AFL-CIO, May 2021), https://aflcio.org/reports/death-job-toll-neglect-2021.
[1021] Richard Fairfax, "On Safety: A Closer Look at OSHA's 'Top 10' Violations – Part III," *Safety and Health Magazine*, April 16, 2021, https://www.safetyandhealthmagazine.com/articles/21080-on-safety-a-closer-look-at-osha-top-10-violations-part-iii.

- October 26, 2020 – Retired oil and gas extraction workers had the highest prevalence of self-reported poor health and were over twice as likely as retirees in other industries to report poor health status. They also suffered a significantly higher prevalence of hearing loss than all other retirees, according to a study conducted by NIOSH researchers. This study, the first to examine the health of retired manual labor miners and oil and gas extraction workers compared with other U.S. retirees, used a 2002-2017 National Health Interview Survey (NHIS) dataset. The NHIS is "a nationally representative survey of civilian, noninstitutionalized adults that collects information on this population's longest-held job, health status, and chronic diseases." The survey also showed that retired oil and gas extraction workers—similar to retired miners—suffer a higher prevalence of lung dysfunction or breathing problems than retirees from other industries. The researchers note that the boom and bust of extraction industries can lead to involuntary retirement and also that lack of a mandatory retirement age can compel oil and gas workers to work until they are physically unable. Researchers also noted that these workers have a higher morbidity during their working years, and this continues into retirement. This study did not have the statistical power to analyze and compare incidence of specific cancers within retirees from different industries. Researchers urged the development of illness prevention strategies and reductions in workplace exposures to prevalent hazards such as noise, silica, and diesel exhaust.[1022]

- October 6, 2020 – In 2018, 94 oil and gas extraction workers were killed on the job, accounting for 72 percent of the fatal work injuries in the "Mining, quarrying, and oil and gas extraction" sector, and 13 deaths more than the previous year. This edition of the AFL-CIO's yearly *Death on the Job: The Toll of Neglect* stated that the reporting year saw "no forward action on critical safety and health problems, including… silica in mining."[1023]

- July 21, 2020 – *E&E News* investigated the increase in oil and gas sites handling hydrogen sulfide across Texas, particularly in the Permian Basin, with a focus on the circumstances of the death of an oil worker and his wife in October 2019.[1024] A "lethal fog" of hydrogen sulfide at levels 137 times the fatal dose killed Jacob Dean, 44, while at work on a repair, and Natalee Dean, 37, who went looking for him when he had not returned home. In the Deans' county alone there were 2,552 oil and gas sites with hydrogen sulfide permits. Between 2015 and 2019, 96 percent of the inspections of these sites statewide only involved verification of whether warning signs and fences were in place, according to the investigation. Though both "OSHA and Texas have regulations meant to protect people against hydrogen sulfide…. the agencies each police different aspects of the industry, and they often don't communicate with each other."

[1022] Tashina Robinson et al., "Health Conditions in Retired Manual Labor Miners and Oil and Gas Extraction Workers: National Health Interview Survey, 2007–2017," *American Journal of Industrial Medicine* 64, no. 2 (2021): 118–26, https://doi.org/10.1002/ajim.23195.
[1023] AFL-CIO, "Death on the Job: The Toll of Neglect, 29th Edition," A National and State-by-State Profile of Worker Safety and Health in the United States, 2020, https://aflcio.org/sites/default/files/2020-10/DOTJ2020_Final_100620_nb.pdf.
[1024] Mike Lee, "Lethal Fog Smothers Texas Oil Sites as Inspections Lag," *E&E News*, July 21, 2020, https://web.archive.org/web/20200722220615/https://www.eenews.net/stories/1063594445.

- May 14, 2020 – In a study of liquid storage tanks for organic chemical additives on 72,023 U.S. fracking well pads, over 95 percent of the total non-methane volatile organic compound (VOC) emissions were Agency for Toxic Substances & Disease Registry (ATSDR) priority-list hazardous substances. Nearly 17 percent of the emissions identified in the study were caused by 15 carcinogenic compounds. Moreover, the researchers found that median well emissions rose dramatically between 2008 and 2014, due to the increase in the amount of chemicals used to fracture each well. Researchers cautioned that limitations they faced in their ability to collect data resulted in an underestimate of emissions. They were not able to access information on proprietary chemicals, which may be toxic and/or carcinogenic, and, of the 2,000 chemicals that were reported, the researchers could only locate complete information for 475. "Therefore, the emissions of the approximately 1500 remaining compounds (including a large number of organic compounds) were not estimated."[1025]

- April 30, 2020 –NIOSH released its 2017 data set from the Fatalities from the Oil and Gas Extraction Industry (FOG) database.[1026] The FOG database was established to collect detailed information about the circumstances related to deaths of workers in oil and gas extraction. For the year 2017, "FOG captured 69 fatalities as a result of 65 incidents, including 3 multiple fatality incidents." As before, Texas was the state with the most fatalities and "well servicing" was by far the most common industry group represented. "Vehicle incidents" and "contact injuries" describe again the majority of the "event type" leading to the fatalities. 2017 data contain further detail about the material being transported during transportation-involved fatalities: the majority involved transportation of "fluids." It is important to note the FOG database is not designed to be comparable with other statistics, e.g. those of the Bureau of Labor Statistics (BLS), but rather to collect detailed information on the fatalities. "The case definitions (i.e. inclusion criteria) differ. Therefore, each system will have a different number of fatalities each year." Importantly, in contrast to BLS, FOG includes all cardiac events where symptoms begin at work.

  > *Cardiac events that begin at work are included in FOG because acute exposure to some chemicals or toxic substances can mimic or induce cardiac events. Also, they are included to support the identification and characterization of factors that may influence the occurrence or outcome of these incidents, such as physically demanding work, and working alone and in remote locations*.

  The release of 2018 data and a forthcoming summary spanning 2014-2018 have been delayed due to the current COVID-19 response.[1027] The 2014 data set was the first of the program and a 2015-2016 data set was released last year. (See entries below for May 13, 2019 and August 24, 2017.)

[1025] Huan Chen and Kimberly E. Carter, "Hazardous Substances as the Dominant Non-Methane Volatile Organic Compounds With Potential Emissions From Liquid Storage Tanks During Well Fracturing: A Modeling Approach," *Journal of Environmental Management* 268 (2020): 110715, https://doi.org/10.1016/j.jenvman.2020.110715.
[1026] National Institute for Occupational Safety and Health (NIOSH), Western States Division, "Fatalities in the Oil and Gas Extraction Industry (FOG) FOG Data - 2017" (U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, 2020), https://www.cdc.gov/niosh/topics/fog/data2017.html.
[1027] A. Ramirez-Cardenas, Personal Communication re: Data Set Release Dates and Report Delay Information, July 24, 2020.

- April 28, 2020 – A worker's foot and lower leg were crushed and permanently injured as a result of a hydraulic line blowout on a Wyoming fracking site, and he filed suit against the fracking company as well as the company that provided the equipment. The worker alleged these entities owed him a "'duty of reasonable care' to ensure the fracking equipment on the job sites was safe and properly maintained," which was violated when they "failed to have regular equipment inspections and repairs done – knowing that not doing so could result in serious injury or death."[1028]

- March 3, 2020 – Using data from a Canadian population-based case-control study, researchers evaluated the associations between workplace exposures of inhaled silica particles and bladder cancer. For this study, fracking workers would presumably be included in the category "Mining and quarrying including oil and gas field occupations," where researchers found over 76 percent were exposed to silica.[1029] Researchers noted that petrochemical workers are documented to have an increased risk of bladder cancer. For this study, they used detailed lifetime occupational histories, and considered latency, concentration, frequency and duration of silica exposure. Results indicated "workers exposed at high frequencies and/or for long durations are at increased risk of bladder cancer." This finding for silica was consistent with an exposure-response relationship.

- January 24, 2020 – The Centers for Disease Control and Prevention (CDC), using data from the 2016 National Violent Death Reporting System, reported on suicide deaths by industry and occupation in 32 states. Researchers identified a total of 15,779 such deaths, including 12,505 (79 percent) men and 3,274 (21 percent) women.[1030] They found that, among the 20 major industry groups analyzed, men in the group "Mining, Quarrying, and Oil and Gas Extraction" had the highest suicide rate, at 54.2 per 100,000 workers. The next highest was Construction at 45.3 per 100,000 workers. The average for men in the entire study population was 27.4 per 100,000 workers. The data was not broken down in order to see the specific rate of oil and gas workers within the larger group.

- December 19, 2019 – In this economic analysis considering the health-related economic impact of using silica sand as the proppant in fracking, researchers found that "the use of each ton of silica proppant results in $123 of external costs from fatalities and nonfatal illness arising due to exposure to silica for a crew handing 60,000 tons of proppants."[1031] They find that replacement with a less harmful, more expensive alternative would be economical if these health-related "externalities" were taken into account.

[1028] Wyoming News Exchange, "Former Worker Sues Fracking Company," *Gillette News Record*, April 28, 2020, https://www.gillettenewsrecord.com/news/wyoming/article_d906cbb9-8499-5004-a22d-24dcfb91c0e6.html.
[1029] Lidija Latifovic et al., "Silica and Asbestos Exposure at Work and the Risk of Bladder Cancer in Canadian Men: A Population-Based Case-Control Study," *BMC Cancer* 20 (2020): 171, https://doi.org/10.1186/s12885-020-6644-7.
[1030] Cora Peterson et al., "Suicide Rates by Industry and Occupation — National Violent Death Reporting System, 32 States, 2016," *Morbidity and Mortality Weekly Report* 69, no. 3 (n.d.): 57–62, https://doi.org/10.15585/mmwr.mm6903a1.
[1031] Sidharth Agrawal and Jeremy M. Gernand, "Quantifying the Economic Impact of Hydraulic Fracturing Proppant Selection in Light of Occupational Exposure Risk and Functional Requirements," *Risk Analysis* 40, no. 2 (2020): 319–35, https://doi.org/10.1111/risa.13419.

- December 17, 2019 – In 2018, the most recent year for which data are available, 94 oil and gas extraction workers died on the job, up from 81 in 2017. These deaths represent over 72 percent of the fatal work injuries in the mining sector.[1032]

- September 11, 2019 – NIOSH's Western States Division staff published a paper outlining the proceedings of a day-long conference for health and safety professionals working in oil and gas exploration and production that addressed controls related to frack sand exposure. Respirable crystalline silica (RCS) is linked to silicosis, lung cancer, kidney and skin diseases. The controls described fell into the categories: elimination through use of alternative proppants; substitution (use of treated quartz sand to minimize aerosol emissions); and engineering controls. The NIOSH group was following up on their 2013 determination that "RCS exposures during these operations exceeded the relevant occupational exposure limits, in some cases by a factor of 10 or more." Though they cited progress on controls implemented to help limit worker exposures in the interim years, authors pointed out limitations to the information presented at the conference. "These include lack of more exhaustive detail related to industrial hygiene sampling data and results as well as the lack of third-party confirmation and public reporting of the control assessments." The authors wrote that few scientific publications on new controls and evaluation of their effectiveness were available. They said the imperative is "that we focus as intently on controls to mitigate the risks for 'long and latent' adverse health outcomes, in this case preventable but extremely serious lung disease, including lung cancer."[1033]

- June 12, 2019 – According to the U.S. Chemical Safety Investigation Board (CSB), the January 2018 explosion of a natural gas rig in southwestern Oklahoma, which killed five workers during the drilling process, was caused by the failure of two protective barriers designed to prevent uncontrolled gas blowouts. As a consequence, a mixture of mud and gas blew upwards out of the well, and the gas ignited and exploded. These mechanical failures, determined the CSB investigators, were, in turn, the result of significant lapses in safety protocols, including warning alarms that did not sound. All five workers who died were trapped inside the driller's cabin when fire blocked both exit doors. This problem, inherent to the design of the cabin, is not exceptional. The CSB investigation found that "there is no guidance to ensure that an emergency evacuation option is present onboard these rigs or can protect workers in the driller's cabin from fire hazards."[1034, 1035] This accident remains one of the worst oil field incidents in U.S. history.

[1032] U.S. Bureau of Labor Statistics, "Fatal Occupational Injuries in Private Sector Mining, Quarrying, and Oil and Gas Extraction Industries," 2019, https://www.bls.gov/charts/census-of-fatal-occupational-injuries/fatal-occupational-injuries-private-sector-mining.htm.

[1033] Eric J. Esswein et al., "Respirable Crystalline Silica Is a Confirmed Occupational Exposure Risk During Hydraulic Fracturing: What Do We Know About Controls? Proceedings From the Silica in the Oilfield Conference," *Journal of Occupational and Environmental Hygiene* 16, no. 10 (2019): 669–74, https://doi.org/10.1080/15459624.2019.1652757.

[1034] U.S. Chemical Safety and Hazard Investigation Board, "Gas Well Blowout and Fire at Pryor Trust Well 1H-9," Investigative Report, June 12, 2019, http://www.nteps.com/images/documents/Pryor_Trust_Report_FINAL_FOR_PUBLICATION_opt.pdf.

[1035] U.S. Chemical Safety and Hazard Investigation Board.

- May 13, 2019 – NIOSH released a data set covering 2015-2016 from the FOG database, capturing "92 fatalities as a result of 79 incidents, including eight multiple fatality incidents."[1036] Sixty-three of these fatalities occurred in 2015 and 29 in 2016. Forty-five of the 92 occurred in Texas, 13 in North Dakota, 8 in Oklahoma, and 5 in New Mexico. Fifty-four of the workers who were killed worked in "well servicing," and 18 in "drilling operations." Twenty-six of the fatalities involved a "vehicle incident," 22 involved a "contact injury" (crushed or struck), and 13 involved explosions. Other variables within the database describing the fatalities include ages of victims and their years of experience, whether they were working unobserved and/or alone, and the circumstances surrounding the multiple fatality incidents. Also noted is whether the information in any given category is unknown.

- April 25, 2019 – In 2017, 81 oil and gas extraction workers died on the job, accounting for 72 percent of the fatal work injuries in the mining sector, which, overall, has a fatality rate nearly four times the national average.[1037] There were 18 more fatal occupational injuries in oil and gas extraction industries than the previous year.[1038] (The 29th edition of this AFL-CIO report, covering 2018, appeared on October 6, 2020; see *Emerging Trends*.)

- February 19, 2019 – An investigation into the death of oil worker Dennis Mason by *E&E News* shows how inhalation of toxic vapors is systematically overlooked as a possible cause of workplace mortality and "indicates that more than four years after worker safety officials started warning of the lethal dangers of inhaling petroleum gases, the danger is still ignored in some corners of the oil patch."[1039] NIOSH has linked at least 13 oil worker deaths to inhalation of petroleum gases, such as butane and propane. However, because medical examiners do not always test for the substances, and attribute the deaths to "natural causes," there are likely more. In this case, OSHA investigators immediately suspected that Dennis Mason was killed by toxic vapors and sent information and materials to the responsible Oklahoma state medical examiner, but state officials said they did not receive them. These materials included a paper by an occupational medicine specialist describing how exposure to high concentrations of hydrocarbon gases and vapors in an oxygen-deficient atmosphere can result in sudden cardiac death among oil and gas extraction workers. Instead, the medical examiner tested only for illegal drugs and alcohol before attributing his death to natural causes.

- February 13, 2019 – A series of catastrophic explosions and fires at a gas-processing facility in Pascagoula, Mississippi shut the plant down for six months in June 2016. This

[1036] National Institute for Occupational Safety and Health (NIOSH), Western States Division, "Fatalities in the Oil and Gas Extraction Industry (FOG) FOG Data 2015-2016" (U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, 2020), https://www.cdc.gov/niosh/topics/fog/data2015-2016.html.
[1037] AFL-CIO, "Death on the Job: The Toll of Neglect, 28th Edition," State-by-State Profile of Worker Safety and Health in the United States, 2019, https://aflcio.org/reports/death-job-toll-neglect-2019.
[1038] U.S. Bureau of Labor Statistics, "Injuries, Illnesses, and Fatalities," 2018, https://www.bls.gov/iif/oshwc/cfoi/cfoi-chart-data-2017.htm.
[1039] Mike Soraghan, "Missed Connections Leave Questions in Oil Worker's Death," *E&E News*, February 19, 2019, https://web.archive.org/web/20190219190653/https://www.eenews.net/stories/1060121345.

facility receives raw gas from drilling operations and separates it into natural gas and hydrocarbon liquids, which are used to make petrochemicals. The U.S. Chemical Safety Board's final report identified "thermal fatigue" as the probable cause of the series of conditions leading to the explosions. A "major loss of containment" in a heat exchanger resulted in the release of methane, ethane, propane, and several other hydrocarbons, which subsequently ignited. The report's interactive 3D model showed that the heat exchanger used at the Enterprise Plant, as well as at over 500 other U.S. gas processing facilities, is innately vulnerable to thermal fatigue. The timing of the explosions at the Pascagoula Gas Plant, which occurred shortly before midnight, likely prevented injuries. According to the final report, had the event happened during the day, with many more workers present, the consequences could have been much worse. The report noted that many nearby residents chose to evacuate, and afterwards, a local community organization informed the Board that residents did not know how to respond to the explosions. "They felt uninformed and ill equipped to know if they were in harm's way." The final report's recommendations included the development of a "robust and engaged community alert network."[1040]

- December 21, 2018 – In the decade between 2008 and 2017, 1,566 U.S. workers died from on-the-job injuries in the oil and gas drilling industry and related fields. These figures were derived from data collected by the U.S. Department of Labor's Bureau of Labor Statistics as part of a special investigative report that included participation by the *Texas Tribune*. In a slightly longer overlapping period, OSHA cited companies in the oil and gas extraction industry for 10,873 violations and investigated 552 accidents that had resulted in at least one worker death. Upstream drilling and fracking operations are exempt from safety rules that govern all downstream sectors of the oil and gas industry. Among these are rules that require refineries, petrochemical plants, and other high-hazard operations to adopt procedures to prevent fires, explosions, and chemical leaks. The investigation detailed a number of specific oil and gas industry deaths in Texas, highlighting the various preventative and regulatory failures associated with traumatic injury; exposure to toxic gases, including hydrogen sulfide; and blowout risk and fires.[1041]

- October 11, 2018 – In addition to social isolation and the wide-ranging effects of job-related stress, the physical costs to well pad workers are high, according to a qualitative study on oil workers' social, emotional, and psychological well-being. The study consisted of in-depth interviews with 14 oil industry workers in Alberta, Canada. Twelve were men and two were women. Thirteen of the fourteen workers were employed by third-party contractors. They included heavy-equipment operators, surveyors, health and safety specialists, environmentalists, biologists, wireline engineers, derrick hands, consultants, and drillers. All were rotational workers. Rotational work involves travel to

[1040] U.S. Chemical Safety and Hazard Investigation Board, "Loss of Containment, Fires, and Explosions at Enterprise Products Midstream Gas Plant," Case Study (CSB, February 13, 2019), https://www.csb.gov/assets/1/6/final_case_study_-_enterprise.pdf.
[1041] Jim Morris, "Death in the Oilfields: Fossil Fuel Boom Brings Mounting Risk of Death, Injuries," *The Texas Tribune*, December 21, 2018, https://www.texastribune.org/2018/12/21/death-oilfields-fossil-fuel-boom-brings-mounting-risks/.

various oil fields and working extended shift schedules, which typically involves 21 consecutive days of work followed by three days off. Most of the respondents said they experienced physical pain on a somewhat regular basis. These findings corroborate the results of other studies reviewed by the authors. "Rotational oil field workers are vulnerable to personal, social, and economic stressors that may result in degraded wellbeing…. As we explored here, 'good jobs' in the patch come at a steep psychosocial and physical health cost to the labourers."[1042]

- October 10, 2018 – The most "cohesive explanation yet" for one of the worst oil field accidents in U.S. history, the January 2018 Oklahoma well fire which killed five workers, came from a lawsuit based on dozens of depositions. OSHA had sought penalties but did not offer an explanation, and the U.S. Chemical Safety Board stated plans to issue a report over a year later. (See Emerging Trend 6 in the front matter of this report, regarding the findings of the final report.) The factors explained in the lawsuit included ignoring warnings about using a cheaper and lighter drilling mud, and a broken and locked door out of which the five workers may have been able to escape.[1043] The operating company blamed contractors.[1044] (See also entry below for August 16, 2018.)

- September 12, 2018 – In 2016, oil and gas pipeline construction workers died on the job 3.6 times more often than the average U.S. worker, as determined by the first independent investigation to compile and present fatality rates for those who build oil and gas pipelines in the United States. That same year oil and gas pipeline construction workers had the highest death rate and number of deaths for those employed in these jobs since 2012. "If we add the deaths of workers whose job it is to maintain and monitor the pipelines as they carry the fuels (pipeline transport), 2016 was the deadliest year for oil and gas pipeline workers since 2009."[1045] Pipeline worker deaths occurred from crushings, fires, and heat exhaustion. The number of miles of U.S. pipelines carrying oil and other hazardous liquids tripled from 2006 to 2016, and newer pipelines are less safe than old ones. Pipelines built after 2010 suffer failures at a higher rate than pipelines built "at any time in the last century," with pipelines carrying natural gas over five times more disaster-prone. The author made available her complete methodology and references for the project, with a discussion of her methodology and other data sources, including strengths, weaknesses, and comparability. Her stated intention in building a first-of-its kind oil and gas pipeline fatality report was to be "as straightforward and replicable as possible."[1046]

[1042] Alysia C. Wright and Yannick Griep, "Burning the Midnight Oil: Examining Wellbeing and Vulnerability in Alberta's Oil Patch," *The Extractive Industries and Society* 6, no. 1 (2019): 77–84, https://doi.org/10.1016/j.exis.2018.10.001.
[1043] Mike Soraghan, "Okla. Company Scrimped Before Deadly Well Fire," *E&E News*, October 10, 2018, https://web.archive.org/web/20181010202924/https://www.eenews.net/stories/1060102139.
[1044] Mike Soraghan, "Well Operator in Fatal Fire Blames Contractors," *E&E News*, October 23, 2018, https://web.archive.org/web/20181023190205/https://www.eenews.net/stories/1060104019.
[1045] Antonia Juhasz, "Death on the Dakota Access," *Pacific Standard*, September 12, 2018, https://psmag.com/magazine/death-on-the-dakota-access.
[1046] Antonia Juhasz, "Methodology for Calculating Fatality Rates," *Pacific Standard*, September 12, 2018, https://psmag.com/magazine/methodology-for-calculating-fatality-rates.

- August 20, 2018 – Nearly 1,000 workers have been killed in the ten years since hydraulic fracturing and horizontal drilling technologies rapidly expanded, although the current oil and gas worker fatality rate is down from its earlier high at seven times higher than across all industries. Persistent fatality risk factors include the practice of manual tank gauging, vehicle crashes, and inexperienced workers.[1047]

- August 16, 2018 – On January 22, 2018, five workers were killed during the drilling of a gas well in Pittsburg County, Oklahoma. While the drill pipe was being lifted, a mixture of mud and gas blew upwards out of the well, and the gas subsequently ignited and exploded. A "factual update" as part of the ongoing investigation by the U.S. Chemical Safety Board found that a piece of safety equipment designed to control the release of fluids from the well was unable to fully close on the day of the accident and that other safety corners had been cut.[1048]

- April 29, 2018 – Improper or inadequate use of personal protective equipment was of highest concern in a survey of industry workers and regulators that was designed to find the frequency of "failure incidents" and near misses at wellhead sites. Workers and regulators also cited spills of flowback water due to equipment failure as a major concern, with regard to the welfare of both workers and the general public, as these spills "occur more frequently than any other scenario examined in this study."[1049]

- April 26, 2018 – There were 63 deaths in oil and gas extraction in 2016, as reported in the 2018 edition of the AFL-CIO report, *Death on the Job, The Toll of Neglect.* The fatality rate for the overall mining sector, which includes oil and gas extraction, was 10.1 per 100,000 workers, nearly three times the national average. These 63 deaths in oil and gas accounted for 71 percent of the total number of fatal work injuries in the mining sector.[1050]

- March 21, 2018 – The trade publication, *Industrial Safety & Hygiene News*, published a summary of January 2015 to February 2017 oil and gas extraction worker "incidents," which included 481 hospitalizations and 166 amputations. The article outlined the data gaps and limitations that make accurate tallies of severe injuries in upstream oil and gas operations hard to calculate:

    - State-run OSHA programs are not included in the count.

[1047] Pamela King, "Even 1 Death Is Too Many. What Does It Take to Get to 0?," *E&E News*, August 20, 2018, https://web.archive.org/web/20180820182924/https://www.eenews.net/stories/1060094701.
[1048] U.S. Chemical Safety Board, "CSB Releases Factual Update on Blowout and Fire at Pryor Trust Gas Well in Pittsburg County, Oklahoma," Press Release (CSB, August 16, 2018), https://www.csb.gov/csb-releases-factual-update-on-blowout-and-fire-at-pryor-trust-gas-well-in-pittsburg-county-oklahoma-/.
[1049] Noura Abualfaraj, Patrick Gurian, and Mira Olson, "Frequency Analysis of Failure Scenarios from Shale Gas Development," *International Journal of Environmental Research and Public Health* 15, no. 5 (April 29, 2018): 885, https://doi.org/10.3390/ijerph15050885.
[1050] AFL-CIO, "Death on the Job: The Toll of Neglect, 27th Edition," Workplace Health and Safety, 2018, https://aflcio.org/reports/death-job-toll-neglect-2018.

- Reporting errors and underreporting are common. Based on workers compensation data, underreporting is estimated at 50 percent; self-reported incidents may lack crucial detail or information.
- OSHA jurisdiction does not cover incidents that occur on public streets, highways, or during commuting.
- Trucking/hauling related incidents may be listed under other [National Association of Insurance Commissioners] codes.[1051]

- December 6, 2017 – Two occupational fatalities and numerous injuries resulted from explosions and fires along oil and gas pipelines in Colorado in the time since two men were killed at home from such a blast in April 2016, according to a *Denver Post* investigation. One contract worker was killed and two others were injured in May while they "were changing 'dump lines' and 'one or more tanks exploded,' according to a report filed in [Colorado Oil and Gas Conservation Commission's] database." Another worker died of his burn injuries from a flash fire in November that broke out during work on a pipeline. "The COGCC did not receive a report on this incident… because the pipeline was a 'gathering line' outside the agency's regulatory purview." The investigation documented additional gaps in regulatory oversight and responses to deaths and injuries.[1052]

- October 1, 2017 – An investigation by the *Toronto Star*, the *National Observer*, *Global News,* and four Canadian journalism schools reported on hydrogen sulphide (H_2S)-related health threats and incidents (including one occupational death) in Saskatchewan, and government and industry failure to prevent, warn, and respond to this threat. The more than 50 reporters involved "examined thousands of industry and government documents, analyzed terabytes of data and delved into dozens of freedom-of-information requests," documenting, for example, the existence of government data describing H_2S "hotspots" across the province, that were never released to the public despite agency deliberations. In addition, reporters wrote,

  > Ministry and industry met four times between 2012 and 2014 to plot strategy, including emergency planning zones, a public communications document, a code of practice and a licensing regime for high-risk, single-well batteries. Those plans were never adopted, a ministry statement confirms.

  An industry salesman was killed in 2014 while taking samples. A valve broke and the concentration of H_2S in the spewed fluids, according to the company, "was estimated at 40,000 parts per million, more than enough to bring near-instant death." The

[1051] Industrial Safety & Hygiene News, "Gaps in Oil & Gas Extraction Work Fatalities and Severe Injury Statistics," March 21, 2018, https://www.ishn.com/articles/108304-gaps-in-oil-gas-extraction-work-fatalities-and-severe-injury-statistics.
[1052] Bruce Finley, "A Dozen Fires and Explosions at Colorado Oil and Gas Facilities in 8 Months Since Fatal Blast in Firestone," *The Denver Post*, December 6, 2017, sec. Business, http://www.denverpost.com/2017/12/06/colorado-oil-gas-explosions-since-firestone-explosion/.

investigation found that four months after the death, "a secret ministry report listed 161 facilities 'that may be in violation of (the ministry's) sour gas emission control.'"[1053]

- August 24, 2017 – NIOSH's Fatalities in Oil and Gas Extraction (FOG) database identified 88 fatal incidents accounting for 101 fatalities, for the year 2014. In ten of the 88 incidents, more than one worker was fatally injured. The FOG database was established to collect detailed information about deaths related to U.S. oil and gas extraction. The report, which represents only a portion of the deaths that occurred in the industry due to the focus and limitations of the database, aims to provide a deeper understanding of the circumstances of the fatalities, such as the industry group the worker was employed by, and operations and types of activities occurring at the time of the fatal incident. The majority of fatalities in FOG, 45 percent, involved workers employed by servicing companies. These servicing company worker fatalities occurred throughout oil and gas extraction operations: completions (14 fatalities), production (11 fatalities), and well servicing, workover, or intervention (5 fatalities). The industry group responsible for the second highest number of fatalities was drilling companies, at 27 percent, with most of those deaths occurring during drilling operations (20 fatalities).[1054]

- May 30, 2017 – In a "rare, but not unprecedented" case, the U.S. Environmental Protection Agency (EPA) opened an investigation of air emissions from two North Dakota oil well sites where worker deaths occurred in 2012 and 2014. EPA requested information from both companies to determine Clean Air Act compliance on the day of the deaths. According to the *E&E News* report, it was not clear whether the agency was "looking at civil or criminal sanctions." Both workers, who were "flow testers," "assigned to regularly measure tank levels by hand," were found dead near tank hatches.[1055] (No further information could be located on this investigation.)

- April 28, 2017 – Fatality rates for oil and gas extraction workers associated with falls increased two percent per year during 2003–2013, according to the Centers for Disease Control and Prevention's *Morbidity and Mortality Weekly Report.* These 63 fatal falls represented 15 percent of the fatal events among this group in the time period. The majority of those who were killed by falls worked for drilling contractors. In the vast majority of cases, "fall protection was required by regulation, but it was not used, was used improperly, or the equipment failed." Authors noted several limitations of their

[1053] Robert Cribb et al., "That Rotten Stench in the Air? It's the Smell of Deadly Gas and Secrecy," *Toronto Star*, October 1, 2017, https://www.thestar.com/news/canada/2017/10/01/that-rotten-stench-in-the-air-its-the-smell-of-deadly-gas-and-secrecy.html.
[1054] Sophia Ridl, Kyla Retzer, and Ryan Hill, "Oil and Gas Extraction Worker Fatalities 2014; NIOSH Fatalities in Oil and Gas Extraction (FOG) Database" (Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH), 2017), Oil and gas extraction worker fatalities 2014; NIOSH fatalities in oil and gas extraction (FOG) database.
[1055] Mike Soraghan, "EPA Investigating Emissions in Tank Deaths," *E&E News*, May 30, 2017, https://web.archive.org/web/20170530150506/https://www.eenews.net/stories/1060055258.

report, such as the lack of information on self-employed workers and lack of detail in some fatality reports.[1056]

- April 26, 2017 – The 2017 edition of the AFL-CIO report, *Death on the Job: The Toll of Neglect,* which reported on the year 2015, showed that, although the number of deaths in the oil and gas extraction industries decreased compared to 2014 (89 compared to 144), employment in oil and gas extraction also decreased from 613,783 in 2014 to 533,184 in 2015. The deaths in the oil and gas extraction industries "accounted for 74% of the fatal work injuries in the mining sector." Referring to the challenges of getting a firm handle on statistics in this industry, the report stated that, "[f]atality rate data for the oil and gas industry are limited, but available data during the past seven years show fatality rates in oil and gas extraction that are four to seven times the national fatality rate." Further, "[n]ot surprisingly, states with large amounts of oil and gas activity also have high job fatality rates." Citing the continuing problem of assigning cause of death in the case of possible inhalation of toxic fumes, the report stated, "[w]hile some deaths are appropriately classified as inhalation deaths, others can be labeled as cardiac arrhythmia or respiratory failure, without further investigation as to whether the health event was induced by acute chemical exposure." As in previous years, the report expressed concerns about the regulatory gaps in controlling a range of potentially fatal hazards in the industry.[1057]

- February 1, 2017 – Caused by exposure to silica particles or dust, silicosis is a progressive, autoimmune disease that scars lung tissue and restricts the ability to breathe. Any level of exposure to respirable crystalline silica can trigger silicosis. A special report on the history of silicosis in the *Journal of Environmental Health* provided background on silicosis as a workplace threat in various industries and identified drilling and fracking operations as a source of contemporary exposure. The report predicts a future cluster of silicosis among well pad workers, noting that research has already identified "unacceptable levels" of silica dust in air samples collected at fracking operations and that workers are seldom offered appropriate respiratory equipment to prevent exposure. Fracking "has the potential for future clusters of silicosis cases to emerge."[1058]

- February 1, 2017 – University of Tennessee Civil and Environmental Engineering faculty investigated the occupational inhalation risks from the emissions of chemical storage tanks in 60,644 fracking wells. They also analyzed the combined occupational inhalation risks caused by open flowback pits and the storage tanks. They used AERMOD, the air pollution dispersion modeling system developed by the American Meteorological Society and EPA, and inhalation risk assessment to determine potential acute non-cancer, chronic non-cancer, acute cancer, and chronic cancer risks. Their results showed the percentage

[1056] Krystal L. Mason et al., "Occupational Fatalities Resulting from Falls in the Oil and Gas Extraction Industry, United States, 2005–2014," *MMWR. Morbidity and Mortality Weekly Report* 66, no. 16 (April 28, 2017): 417–21, https://doi.org/10.15585/mmwr.mm6616a2.
[1057] AFL-CIO, "Death on the Job: The Toll of Neglect, 26th Edition," 2017, https://aflcio.org/reports/death-job-toll-neglect-2017.
[1058] M. Thomas Quail, "Overview of Silica-Related Clusters in the United States: Will Fracking Operations Become the Next Cluster?," *Journal of Environmental Health* 79, no. 6 (February 2017): 20–27.

of wells presenting these risks were 12.41, 0.11, 7.53, and 5.80, respectively. They also found that the storage tanks presented the majority of the cancer risks, and the non-cancer risks were associated primarily to the open pits. The known human carcinogen formaldehyde was "the dominant contributor" to both acute (4,267 wells) and chronic (3,470 wells) cancer risk. Authors also reported that volatile organic compound (VOC) emissions from nearby wells and other on-site sources means that the data used in their study "were lower than reported concentrations from field measurements where higher occupational inhalation risks for exposure may be expected."[1059]

- January 19, 2017 – A group of Canadian physicians published a report documenting ten intentional intoxications from the ingestion of fracking fluid. Each individual survived, which the authors attribute to "[r]apid case finding and diligent contact tracing." Their report, published in the *American Journal of Kidney Diseases,* focused on this appropriate response and treatment, but also described the "outbreak" challenge from a public health perspective and emphasized the need for prevention education and "requiring secure storage of these products." Though the professions or workplaces of the patients are not described, presumably they were oil and gas industry workers with easy access to fracking fluid.[1060]

- September 25, 2016 – A four-chapter investigative series by the *Denver Post* explored in detail Colorado's 12-year record of an oil and gas worker dying, on average, every three months. The piece documented the obstacles present in even clarifying the occupational mortalities owing to the differing reporting practices of the Bureau of Labor Statistics, OSHA, and state officials. "Regulation is so disjointed that no one can even agree on the number of workers killed on the job." Investigating the details of the deaths through any available records, the *Post* described a "regulatory vacuum," as well as "little consequence" to the industry when deaths (or worksite violations) occur. Worker death circumstances examined in the piece included electrocutions, falls and collapsed structures, crushings by equipment, explosions, and a drowning in frack sand. The *Post* also identified five lawsuits over 15 years "in which workers alleged that they were punished for reporting injuries or safety hazards."[1061]

- April 27, 2016 – According to the 2016 edition of the AFL-CIO report, *Death on the Job: The Toll of Neglect,* the fatality rate for workers in the oil and gas extraction industries is nearly five times the national average, and the states with prominent oil and gas industries are among the most dangerous states to work. In addition, the report emphasized, the industry has been exempted from some critical OSHA standards, including that for carcinogenic benzene. The report also emphasized the danger of silica dust exposure in hydraulic fracturing-related work and the significant delays in

[1059] Huan Chen and Kimberly E. Carter, "Modeling Potential Occupational Inhalation Exposures and Associated Risks of Toxic Organics from Chemical Storage Tanks Used in Hydraulic Fracturing Using AERMOD," *Environmental Pollution* 224 (May 2017): 300–309, https://doi.org/10.1016/j.envpol.2017.02.008.
[1060] David Collister et al., "A Methanol Intoxication Outbreak From Recreational Ingestion of Fracking Fluid," *American Journal of Kidney Diseases* 69, no. 5 (May 2017): 696–700, https://doi.org/10.1053/j.ajkd.2016.10.029.
[1061] R. J. Sangosti and John Ingold, "Drilling Through Danger," *The Denver Post*, September 25, 2016, http://extras.denverpost.com/oil-gas-deaths/index.html.

controlling workers' exposures in these operations. "Oil and gas extraction is subject to OSHA general industry and construction regulations, none of which are designed to address the particular safety and hazards in the oil and gas industry…. The escalating fatalities and injuries in the oil and gas extraction industry demand intensive and comprehensive intervention," the report stated.[1062]

- April 21, 2016 – According to an updated report from the Bureau of Labor Statistics, fatal work injuries in oil and gas extraction industries in 2014 reached a new high of 144.[1063]

- February 29, 2016 – *Inside Energy's* report on high rates of hydrocarbon vapor poisoning among oilfield workers noted that an outdated reliance on manual measurements rather than automated monitoring contributes to ongoing toxic exposures of workers. Under federal oil and gas regulations, oil companies are effectively required to send workers "up on oil and gas tanks to manually measure crude oil, putting them at risk." The report explained that the Bureau of Land Management (BLM) allows just one kind of automated measurement. The method is expensive and uncommonly used: "there are only 1,500 in use, compared to more than 83,000 oil tanks on federal land. By being so inflexible, BLM's outdated rules make it very hard to use safer oil measuring devices while making manual oil tank measurement—which endangers workers—the most viable option for companies."[1064]

- February 19, 2016 – The fatal injuries of a backhoe operator who struck and hit an unmarked, high-pressure gas line in July 2015 prompted an investigation by *StateImpact* in Pennsylvania. The news group noted that "there are no local, state or federal rules on how deep the lines should be buried underground, or even if they're buried at all. There are no standards for building and maintaining the lines. They don't have to be marked. And the operator of the line doesn't have to participate in PA One Call [a statewide communications system for preventing damage to underground facilities], which led to the fatality in Armstrong County."[1065]

- January 15, 2016 – In a publication in Centers for Disease Control's *Mortality & Morbidity Weekly Report*, researchers urged local and state epidemiologists and medical examiners to not overlook hydrocarbon exposure as an underlying cause of death in gas and oil field workers. "Health and safety professionals need to recognize and act on nonfatal warning signs and symptoms, such as dizziness, confusion, immobility and collapse in oil and gas workers who might have been exposed to high concentrations of

[1062] AFL-CIO, "Death on the Job: The Toll of Neglect, 2016," 2016, http://www.aflcio.org/Issues/Job-Safety/Death-on-the-Job-Report.
[1063] U.S. Bureau of Labor Statistics, "Revisions to the 2014 Census of Fatal Occupational Injuries (CFOI)," April 21, 2016, http://www.bls.gov/iif/cfoi_revised14.htm.
[1064] Emily Guerin, "'Senseless Exposures': How Money and Federal Rules Endanger Oilfield Workers," *Inside Energy*, February 29, 2016, http://insideenergy.org/2016/02/29/senseless-exposures-how-money-and-federal-rules-endanger-oilfield-workers/.
[1065] Susan Phillips, "Worker Dies in Pipeline Accident, PUC Steps up Calls for Reform," *State Impact Pennsylvania*, February 19, 2016, https://stateimpact.npr.org/pennsylvania/2016/02/19/worker-dies-in-pipeline-accident-puc-steps-up-calls-for-reform/.

[hydrocarbon gas vapors] and to [oxygen]-deficient atmospheres." Only three of nine deaths that occurred between 2010 and 2015 in the oil and gas fields west of Appalachia were ruled by coroners to have resulted from exposure to gas vapors, although all nine had opened hatches of storage tanks and were exposed to hydrocarbon vapors and oxygen-deficient air.[1066] The *Pittsburgh Post-Gazette* quoted emeritus professor at the University of Pittsburgh Bernard Goldstein saying, "Occupational health experts also suspect that some deaths involving fires, falls, crashes and mishandling of equipment have resulted from faulty judgement or 'wooziness' associated with hydrocarbon vapor exposure … [b]ut that underlying factor rarely shows up in fatality reports."[1067]

- December 14, 2015 – As reported in the *Guardian,* the suicide rate in the Canadian province of Alberta spiked by 30 percent spike in the first half of 2015, possibly linked to the boom-and-bust cycle of the fracking industry. At the time of reporting, 40,000 jobs had been lost in Alberta since the drop in oil prices in late 2014. Mental health professionals interviewed for the report included Edmonton social worker Leonard McEwan, who specializes in clinical crises intervention and whose patients include those directly or indirectly employed in the oil fields, noticed a sharp increase in suicides after the recent plunge in oil prices. As revealed in the investigative report, three in every four Alberta suicides are male and the vast majority are under 55. Gladys Blackmore, executive director of a mental health program that targets those employed in the industry, believes that young, male workers "living high-risk lifestyles, often in work camps, where they 'fly-in/fly-out' for up to 24 days at a time" are particularly vulnerable.[1068]

- November 7, 2015 – The *Denver Post* reported on a "new federal database that was developed to more precisely capture the deadly nature of oil and gas extraction." For Colorado, the national Fatalities in Oil and Gas Extraction (FOG) database contained two additional oil and gas worker deaths for 2014 than did the Bureau of Labor Statistics. "'We knew from the Bureau of Labor Statistics data about the basics of what's killing workers,' said Kyla Retzer, an epidemiologist who led the effort to compile the FOG report. 'We just wanted to be more in-depth in finding out what were the types of operations and equipment were involved in these deaths.'"[1069] (See entry for August 24, 2017 above for official report.)

- November 4, 2015 – San Antonio's *Express-News* Editorial Board called for specific actions to address Texas's status "a national leader in oil field deaths." The Board wrote

[1066] Robert J. Harrison et al., "Sudden Deaths Among Oil and Gas Extraction Workers Resulting from Oxygen Deficiency and Inhalation of Hydrocarbon Gases and Vapors — United States, January 2010–March 2015," *Morbidity and Mortality Weekly Report* 65, no. 1 (2016): 6–9.
[1067] Anya Litvak, "Vapors Linked to Oxygen Depletion Present Hazard for Oil, Gas Workers," *Pittsburgh Post-Gazette*, January 24, 2016, http://powersource.post-gazette.com/powersource/policy-powersource/2016/01/25/Vapors-linked-to-oxygen-depletion-present-hazard-for-oil-gas-workers/stories/201601220095.
[1068] Omar Mouallem, "The Boom, the Bust, the Darkness: Suicide Rate Soars in Wake of Canada's Oil Crisis," *The Guardian*, December 14, 2015, https://www.theguardian.com/world/2015/dec/14/canada-oil-production-crisis-suicide-alberta?CMP=share_btn_fb.
[1069] Monte Whaley, "Colorado Oil Deaths Greater in 2014 than Previously Calculated," *The Denver Post*, November 7, 2015, http://www.denverpost.com/2015/11/07/colorado-oil-deaths-greater-in-2014-than-previously-calculated/.

that federal fines are too low and unchanged since 1991 and that there is no Level 1 trauma center south of San Antonio near the region's oil- and gas-producing counties.[1070]

- September 17, 2015 – The Bureau of Labor Statistic reported that the number of fatal work injuries in oil and gas extraction industries rose 27 percent between 2013 and 2014.[1071]

- September 15, 2015 – E&E Publishing's *EnergyWire* reported on the potentially deadly risk of exposure to vapors from oil and gas field storage tanks, including deaths that were officially attributed to cardiac arrest, though inhalation of toxic gases and lack of oxygen played a role, as demonstrated in subsequent litigation. The reporter gave detail on the circumstances of several of the deaths, including that of a long-haul trucker who had heart disease and was diabetic, and whose death was classified as natural. "But he didn't suffer a heart attack that day, or a diabetic episode. Medical experts said he likely wouldn't have died outside the toxic atmosphere on the catwalk." A Denver cardiologist testified that "there was no other reason for him to have died that day."[1072] (NIOSH has subsequently targeted outreach to medical examiners to improve their recognition of this hazard and potential cause of death; see above.)

- September 5, 2015 – In partnership with Rocky Mountain PBS I-News, *The Durango Herald* reported on the oil and gas industry's varied practices in their handling of silica sand with regard to worker protection. In 2012 the National Institute for Occupational Safety and Health issued an alert concerning workers at fracking sites being exposed to silica dust at levels that exceeded occupational exposure limits. Industry has resisted updates to the standards. The *Herald* report addressed technological and work practice controls to reduce exposure on the part of some companies. Still, authors wrote, silicosis "can hide for a decade before causing symptoms. No one knows how many oil and gas workers may have already been exposed."[1073]

- June 29, 2015 – An investigation by the Center for Public Integrity (CPI) found that lung-damaging silica is not sufficiently regulated to prevent silicosis (which is incurable and has no effective treatment) or lung cancer in the workplace. Rules governing occupational exposure to silica dust are far outdated, and advocacy efforts to tighten them are four decades old. At particular risk, say the authors, are workers in oil and gas fields where silica sand is used in fracking operations. Citing research by NIOSH, the CPI team

[1070] Express-News Editorial Board, "Take Care of the State's Oil, Gas Workers," *MySanAntonio.Com*, November 4, 2015, http://www.mysanantonio.com/opinion/editorials/article/Take-care-of-the-state-s-oil-gas-workers-6611077.php.
[1071] U.S. Department of Labor, Bureau of Labor Statistics, "National Census of Fatal Occupational Injuries in 2014 (Preliminary Results)," News Release, September 17, 2015, https://web.archive.org/web/20161218034553/https://www.bls.gov/news.release/archives/cfoi_09172015.pdf.
[1072] Mike Soraghan, "SAFETY: How Shale Oil Can Kill," *E&E News*, September 14, 2015, https://web.archive.org/web/20150918032438/http://www.eenews.net/stories/1060024589.
[1073] Anna Boiko-Weyrauch, "Oil, Gas Industry Responding to Threat of Worker Lung Disease," *Durango Herald*, September 5, 2015, https://www.durangoherald.com/articles/oil-gas-industry-responding-to-threat-of-worker-lung-disease/.

noted that nearly 80 percent of the air samples on the well pads were above the recommended exposure limit for silica dust.[1074]

- June 15, 2015 – *EnergyWire* examined issues surrounding exposure to crystalline silica from frack sand mining, which is a health concern to those living near mines and to those working in the industry. Families living near industrial sand mining reported that their health has been compromised by sand mine development and are concerned that companies are not properly monitoring their extraction sites. The article noted that OSHA is working on a new exposure rule for workers that the agency estimates would save nearly 700 lives and prevent 1,600 new cases of silicosis annually. The oil and gas industry is fighting the rule because of the cost associated with complying with a more stringent permissible exposure limit. Crispin Pierce, public health researcher at the University of Wisconsin in Eau Claire, is in the midst of a three-pronged research project to look at the industry's air effects. Among other findings, his project's air monitors around sand plants have found consistently finding higher readings than the Wisconsin Department of Natural Resources' reported regional values.[1075]

- June 15, 2015 – In an update, NIOSH noted that silicosis death rates are rising again, reversing an earlier, decade-long decline. In the list of job tasks with known high silica exposures, the update named hydraulic fracturing of gas and oil wells. These results are particularly concerning in light of earlier research showing significant under-detection of silicosis among deceased workers with known exposure to silica dust.[1076]

- June 13, 2015 – Reporting on North Dakota's fracking boom, the Center for Investigative Reporting found that the major oil companies have largely written the rules governing their own accountability for accidents. Deeply entrenched corporate practices and weak federal oversight, according to the report, have led to high injury and death rates and a shift of assigned responsibility to others. Using data from U.S. and Canadian regulators, the journalists verified 74 on-the-job deaths among workers in Bakken Shale drilling and fracking operations since 2006. The actual number of deaths is likely higher than currently reported because federal regulators do not have a systematic way to record oil- and gas-related deaths, and OSHA does not include certain fatalities, including those of independent contractors. The report concluded that there was too little oversight from OSHA, that laws to protect workers were outdated, and that there was a culture of self-regulation by the industry.[1077]

- May 29, 2015 – The Centers for Disease Control and Prevention published statistics on work-related fatalities during the fracking boom. The occupational fatality rate among

[1074] Jim Morris, Jamie Smith Hopkins, and Maryam Jameel, "Slow-Motion Tragedy for American Workers," Center for Public Integrity, June 30, 2015, https://publicintegrity.org/inequality-poverty-opportunity/workers-rights/slow-motion-tragedy-for-american-workers/.
[1075] Pamela King, "Frac Sand Towns Question Whether Rules Protect Them against Silica Pollution," *Energy Wire*, June 15, 2015, https://web.archive.org/web/20150621073016/https://www.eenews.net/stories/1060020192.
[1076] Jacek Mazurek and David Weissman, "Silicosis Update," *NIOSH Science Blog* (blog), June 15, 2015, https://blogs.cdc.gov/niosh-science-blog/2015/06/15/silicosis-update/.
[1077] Jennifer Gollan, "In North Dakota's Bakken Oil Boom, There Will Be Blood," *Reveal*, June 13, 2015, http://revealnews.org/article/in-north-dakotas-bakken-oil-boom-there-will-be-blood/.

U.S. oil and gas industry extraction workers between 2003 and 2013 remained an average of seven times higher than among U.S. workers in general (25.1 versus 3.7 deaths per 100,000 workers per year). Within this 11-year period, the industry doubled the size of its workforce and increased drilling rigs by 71 percent. The number of occupational deaths increased 27.6 percent, with a total of 1,189 deaths, but it did not increase as much as the number of workers, resulting in an overall decrease in the fatality rate of 36.3 percent. Transportation accidents and contact with objects and equipment were the most frequent fatal events. Evidence suggests that the increased use of automated technologies on drilling rigs may be contributing to the decline in death rates.[1078]

- April 22, 2015 – The AFL-CIO published data for job injuries, illnesses and deaths in a national and state-by-state profile of worker safety and health in the United States, presenting comparisons by state and industry. For the third year in a row, North Dakota had the highest on-the-job fatality rate in the nation: 14.9 deaths per 100,000 workers, a rate that is more than four times the national average, and which has more than doubled since 2007. The fatality rate in the mining and oil and gas extraction sector in North Dakota was 84.7 per 100,000, which is nearly seven times the national fatality rate of 12.4 per 100,000 in this industry.[1079, 1080]

- April 10, 2015 – In a study that was inclusive of fracking-based extraction but not specific to it, NIOSH researchers updated their investigation into the sudden deaths of nine oil and gas extraction workers found near hatches where hydrocarbons were stored. All nine victims died between 2010 and 2014 and were unobserved or working alone at the time of their deaths. The first report attributed the fatalities to "inhalation of volatile petroleum hydrocarbons."[1081] The update noted that when workers open hatches on production tanks, a plume of hydrocarbon gases and vapors can be rapidly released due to high internal pressure. Exposure to high concentrations of these low-molecular-weight hydrocarbons creates asphyxiation and explosive hazards and can have narcotic effects, resulting in disorientation, dizziness, and light-headedness. The authors cited reports of other sudden deaths following butane and propane inhalation, exposure to which can induce irregular heartbeat, insufficient oxygen supply, and respiratory depression.[1082] As reported by the *Denver Post*, most of the death certificates listed natural causes or heart failure as the cause likely because medical examiners can easily miss signs of toxic inhalation during a routine autopsy. The nomadic nature of the industry presents

[1078] Krystal L. Mason, "Occupational Fatalities During the Oil and Gas Boom — United States, 2003–2013," *Morbidity and Mortality Weekly Report* 64, no. 20 (May 29, 2015): 551–54.
[1079] AFL-CIO, "Death on the Job: The Toll of Neglect, 25th Edition," April 22, 2015, https://aflcio.org/reports/death-job-2016.
[1080] Jana Kasperkevic, "About 150 US Workers Are Killed on the Job Every Day – Report," *The Guardian*, April 29, 2015, sec. US news, http://www.theguardian.com/us-news/2015/apr/29/north-dakota-deadliest-state-workers-third-year-running.
[1081] NIOSH, "Suspected Inhalation Fatalities Involving Workers during Manual Tank Gauging, Sampling, and Fluid Transfer Operations on Oil and Gas Well Sites, 2010-2014," March 15, 2015, https://www.cdc.gov/niosh/topics/fog/SpecialTopic2015.html.
[1082] Bradley King et al., "UPDATE: Reports of Worker Fatalities during Manual Tank Gauging and Sampling in the Oil and Gas Extraction Industry," *NIOSH Science Blog* (blog), April 10, 2015, https://blogs.cdc.gov/niosh-science-blog/2015/04/10/flowback-3/.

obstacles to proper training in tank handling techniques.[1083] NIOSH issued recommendations for worker protections, including respiratory protection training and engineering controls for remote gauging and venting.[1084]

- February 15, 2015 – Burn injuries among North Dakota workers surged to more than 3,100 over the past five years as the area has become the epicenter of a massive drilling and fracking boom, as reported by the *Star Tribune*. Despite the flammability of Bakken crude oil and the danger of oil rig work, North Dakota has no burn centers, and burn victims must be transported out of state, typically to the Minneapolis-St. Paul area some 600 miles away. The article also covered the severe, debilitating, costly, and sometimes fatal aspects of these occupational injuries.[1085]

- February 13, 2015 – NIOSH reported that while silicosis death rates declined between 2001 and 2010, silicosis deaths were still occurring among young persons aged 15 to 44 years old, indicating extremely high exposures to respirable silica dust. Among emerging new settings that put workers at risk for silicosis, the authors named oil and gas extraction industry workers.[1086]

- January 14, 2015 – The *Charleston Gazette-Mail* reported that, due to an increase in workplace deaths that has accompanied the boom in natural gas drilling and production from the Marcellus Shale fields in Northern West Virginia, the Governor there has called for a study aimed at reversing that trend. "Between 2009 and 2013, as the industry boomed in the Marcellus region, 15 natural gas workers died on the job in West Virginia, according to the federal data. During the previous five-year period, from 2004 to 2008, three workers died in West Virginia's oil and gas industry, according to the [U.S. Bureau of Labor Statistics]."[1087]

- January 12, 2015 – Oil and gas production employs less than one percent of the U.S. workforce, but in the past five years it has had more than ten percent of all workplace fatalities from fires and explosions. A review by *EnergyWire* of federal labor statistics last year found the industry had more deaths from fires and explosions than any other private industry. The only "industry" with more fire and explosion fatalities than oil and

[1083] Monte Whaley, "Toxic Vapors Suspected in Deaths of Three Colorado Oil and Gas Workers," *The Denver Post*, May 17, 2015, https://www.denverpost.com/2015/05/17/toxic-vapors-suspected-in-deaths-of-three-colorado-oil-and-gas-workers/.
[1084] The Associated Press, "9 Oil Well Deaths Lead to Warning about Inhaling Chemicals," *The Coloradoan*, May 18, 2015, https://www.coloradoan.com/story/news/2015/05/18/oil-deaths-lead-warning-inhaling-chemicals/27562991/.
[1085] Maya Rao, "Twin Cities Hospitals Are Front Line in Treating Bakken Burn Victims," *Star Tribune*, February 15, 2015, https://www.startribune.com/twin-cities-hospitals-are-front-line-in-treating-bakken-burn-victims/291967611/.
[1086] Ki Moon Bang et al., "Silicosis Mortality Trends and New Exposures to Respirable Crystalline Silica — United States, 2001–2010," *Morbidity and Mortality Weekly Report* 64, no. 5 (February 13, 2015): 117–20.
[1087] Ken Ward Jr., "Tomblin Calls for Study of Increased Deaths from Gas-Drilling Boom," *Charleston Gazette-Mail*, January 14, 2015, https://www.wvgazettemail.com/news/politics/tomblin-calls-for-study-of-increased-deaths-from-gas-drilling/article_21d6342f-c5dd-54ee-bd91-534ece13373a.html.

gas was firefighting, the report stated. These statistics are inclusive of deaths related to fracking operations but are not specific to them.[1088]

- December 26, 2014 – A report in the *Houston Chronicle* illustrated the difficulties oil and gas workers encounter when injured on the job. In one case a worker fell from a rig, injuring his head. Supervisors did not record the accident. After he became too ill to work, he was shifted to other jobs and soon after, sent home. His daughter filed a Worker's Compensation claim, which was denied for "late reporting, no knowledge of injury by employer and no medical reports." The article noted that oilfield injuries are generally undercounted nationally. These include injuries related to drilling and fracking operations as well as those linked to other techniques of extraction.[1089]

- December 4, 2014 – Benzene, a naturally occurring component of crude oil and natural gas, is a known carcinogen, with no known threshold of safety. Although the American Petroleum Institute in 1948 stated that "the only absolutely safe concentration … is zero," the organization since then undertook an intensive campaign to combat strict exposure limits. An investigation by the Center for Public Integrity found that, "[f]or decades, the petrochemical industry spent millions on science seeking to minimize the dangers of benzene.… Taken together, the documents—put in context by interviews with dozens of lawyers, scientists, academics, regulators and industry representatives—depict a 'research strategy' built on dubious motives, close corporate oversight and painstaking public relations."[1090]

- December, 2014 – In a report intended to inform employers and workers about the known hazards that result from hydraulic fracturing and flowback operations, OSHA noted that there is no publicly available worker injury, illness, or fatality data specific for fracking or flowback operations. At the same time, more workers are exposed to fracking- and flowback-related hazards due to the huge increase in the numbers of these operations over the past ten years. "In light of this, OSHA has determined that additional information concerning hydraulic fracturing and flowback operations hazards should be provided to educate and protect workers."[1091]

- November 11, 2014 – University of Wisconsin toxicologist Crispin Pierce documented super-fine dust drifting from facilities that process silica sand for fracking operations. Pierce and his team detected silica dust in ambient air near frac sand operations at levels that exceed EPA air quality standards by a factor of four. Occupational exposure to respirable crystalline silica is linked in adult workers to silicosis, lung cancer, and

[1088] Mike Soraghan, "At Least 16 Drilling Industry Workers Died in Fires, Explosions Last Year," January 12, 2015, https://web.archive.org/web/20150623023615/http://www.eenews.net/stories/1060011452.
[1089] Lise Olsen, "Many Oilfield Injuries Go Unreported," *Houston Chronicle*, December 26, 2014, sec. Houston, https://www.houstonchronicle.com/news/houston-texas/houston/article/Many-oilfield-injuries-go-unreported-5980350.php.
[1090] Kristen Lombardi, "Benzene and Worker Cancers: 'An American Tragedy,'" Center for Public Integrity, December 4, 2014, https://publicintegrity.org/environment/benzene-and-worker-cancers-an-american-tragedy/.
[1091] U.S. Department of Labor, Occupational Safety and Health Administration, "Hydraulic Fracturing and Flowback Hazards Other than Respirable Silica," Guidance Document, 2014, https://www.osha.gov/sites/default/files/publications/OSHA3763.pdf.

pulmonary tuberculosis. Health threats to the general public from frac sand-related air pollution have not yet been studied directly. One of the first investigations of silica dust levels in the community environment, the Wisconsin study will appear next year in the *Journal of Environmental Health*.[1092] (See entry for November 6, 2015 in Sand mining and processing.)

- November 11, 2014 – A high-pressure water line ruptured, killing one worker and seriously injuring two others during the hydraulic fracturing of an oil well in Weld County, Colorado.[1093]

- October 13, 2014 – A legal news publication described the multiple lawsuits alleging that drilling rig workers were not made aware of and protected from asbestos in drilling muds. "Various plaintiffs have testified that they were made to work in an environment where there was asbestos drilling mud dust everywhere from the powder, and that no guidance or protective gear was provided."[1094] Breathing asbestos is definitively linked to asbestosis, lung cancer, and mesothelioma of the pleura.

- October 6, 2014 – Toxicologist Peter Thorne, chair of University of Iowa's Department of Occupational and Environmental Health, warned the Winneshiek County Board of Supervisors about potential community impacts and cancer risks of silica exposure from sand used for fracking operations. Thorne's ongoing investigation, which involves air sampling, risk assessments, and inhalation toxicology studies, focuses on the public health hazards of mining, processing, and storing sand. His team has documented spikes in silica particulate matter related to the transport of the silica sand by rail. The study aims to determine if mining poses an "unacceptable exposure" to the public and quantify the level of risk. For silica-exposed workers, NIOSH continues to identify needed heath protections. Thorne noted, "Workers handling materials should be using respirators, but most are not."[1095]

- September 25, 2014 – The Civil Society Institute's Boston Action Research, in cooperation with Environmental Working Group and Midwest Environmental Advocates, issued a report on the hazards of silica mining. The report noted that frac sand mining is expanding rapidly in the United States and poses a little-understood threat to public health, the environment, and local economies. Given the pace of the drilling and fracking boom, silica extraction could spread to a dozen other states with untapped or largely untapped sand deposits, including Illinois, Maine, Massachusetts, Michigan, Missouri,

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[1092] Rich Kremer, "High Levels Of Super-Fine Dust Are Detected Around Wisconsin Frac Sand Mines," *Wisconsin Public Radio*, November 11, 2014, https://www.wpr.org/high-levels-super-fine-dust-are-detected-around-wisconsin-frac-sand-mines.
[1093] J. Paul, "Brighton Man ID'd as Victim in Fatal Weld County Fracking Blast," *The Denver Post*, November 11, 2014, https://www.denverpost.com/2014/11/14/brighton-man-idd-as-victim-in-fatal-weld-county-fracking-blast/.
[1094] Gordon Gibb, "Major Oil Drilling Enterprise References Drilling Mud Lawsuits in Q2 Report," *LawyersandSettlements.Com*, October 13, 2014, https://www.lawyersandsettlements.com/legal-news/asbestos-drilling-mud/drilling-mud-asbestos-lawsuit-24-20169.html.
[1095] "U of I Researcher Informs Supervisors about Frac-Sand Impact," *Driftless Journal*, October 6, 2014, https://decorahnewspapers.com/Content/Home/Home/Article/U-of-I-researcher-informs-supervisors-about-frac-sand-impact/-2/-2/35735.

New York, North Carolina, South Carolina, Pennsylvania, Tennessee, Vermont, and Virginia. The *International Business Times* published a summary of the findings.[1096, 1097]

- August 29, 2014 – In a peer-reviewed study, NIOSH partnered with oil and gas operators and service companies to evaluate worker exposures to, and internal uptake of, volatile organic chemicals at six sites in Colorado and Wyoming where wells were being prepared for production. The study found benzene in the urine of well pad workers. Benzene is "naturally present in flowback fluids and the time spent working around flowback and production tanks … appears to be the primary risk factor for inhalation exposures." In some cases, airborne concentrations of benzene exceeded the NIOSH Recommended Exposure Limit concentrations and, in a few instances, the American Conference of Governmental Industrial Hygienists' Threshold Limit Value, "when workers performed work tasks near a point source for benzene emissions."[1098]

- July 29, 2014 – As part of an investigation into the health impacts of drilling and fracking on animal health, veterinarian Michelle Bamberger and Cornell biochemist Robert Oswald, published an interview with a twenty-year oil and gas industry worker about his experiences and worker safety. His account included injuries, 16-hour workdays, fatigue, exposure to chemicals, and inadequate health and safety training. "No one out there tells you about stuff that has latency. That is the last thing they are going to do is tell you that something that you are handling will take you out in 20 years or 10 years or cause you some kind of ailment, or you can potentially drag this home to your family."[1099]

- July 14, 2014 – As part of an analysis of safety and research needs associated with drilling and fracking, researchers at the Colorado School of Public Health and the College of Health Sciences at the University of Wyoming documented high injury and on-the-job mortality rates among gas and oilfield workers. The occupational fatality rate was 2.5 times higher than that of the construction industry and seven times higher than that of general industry. By contrast, injury rates were lower than the construction industry, suggesting that injuries are underreported. Researchers documented crystalline silica levels above occupational health standards and identified the existence of other hazards, including particulate matter, benzene, noise, and radiation. The team called for exposure assessments for both chemical hazards and physical hazards that lead to occupational illness (noise, radioactivity); screening and surveillance systems to assess incidence and

[1096] Emily Chapman et al., "Communities At Risk: Frac Sand Mining in the Upper Midwest A Report by Boston Action Research" (Civil Society Institute, September 25, 2014), https://www.civilsocietyinstitute.org/NEWCSI/2014CommunitiesatRiskFracSandMiningintheUpperMidwest.pdf.
[1097] Maria Gallucci, "US Oil & Gas Fracking Boom Could Drive Silica Sand Mining Operations In 12 More States, Environmental Groups Say," *International Business Times*, September 25, 2014, sec. Business, https://www.ibtimes.com/us-oil-gas-fracking-boom-could-drive-silica-sand-mining-operations-12-more-states-1695246.
[1098] Eric J. Esswein et al., "Evaluation of Some Potential Chemical Exposure Risks During Flowback Operations in Unconventional Oil and Gas Extraction: Preliminary Results," *Journal of Occupational and Environmental Hygiene* 11, no. 10 (2014): D174–84, https://doi.org/10.1080/15459624.2014.933960.
[1099] Michelle Bamberger and Robert Oswald, "The Shale Gas Revolution from the Viewpoint of a Former Industry Insider," *New Solutions: A Journal of Environmental and Occupational Health Policy* 24, no. 4 (February 2015): 585–600, https://doi.org/10.2190/NS.EOV.1.

prevalence of occupational illness; industry/academic collaboration to conduct occupational epidemiologic studies; and assessment of the effectiveness of industry interventions to reduce exposures.[1100]

- July 2014 – The British labor journal *Hazards* identified health concerns in the drilling and fracking industry: increased rate of death on the job, toxic releases, silica exposure, and exposure to hydrocarbons and endocrine disruptors. The union that organizes the construction, rig, and transport workers, on which fracking would rely, agreed at its July 2014 national conference to lobby for a moratorium on fracking because "[d]elegates want union members to be made aware of the dangers of fracking and be advised not to work on fracking sites."[1101]

- June 29, 2014, and August 31, 2014 – An initial report and follow-up analysis in *The Columbus Dispatch* examined fire hazards at well pads. In one notable case, malfunctioning hydraulic tubing allowed a well pad fire in Monroe County, Ohio to spread rapidly, prompting evacuations. Local firefighters had neither the correct equipment nor did they know the chemicals they were trying to extinguish. One firefighter was treated for smoke inhalation.[1102, 1103]

- May 19, 2014 – Underscoring the dangerous nature of chemicals used in fracking operations, NIOSH reported that at least four gasfield workers have died since 2010 from acute chemical exposures during flowback operations and warned that flowback operations can "result in elevated concentrations of volatile hydrocarbons in the work environment that could be acute exposure hazards." The agency further noted that such volatile hydrocarbons "can affect the eyes, breathing, and the nervous system and at high concentrations may also affect the heart causing abnormal rhythms."[1104, 1105]

- May 16, 2013 – A NIOSH study revealed that worker exposure to crystalline silica dust from sand used in fracking operations exceeded "relevant occupational health criteria" at all eleven tested sites, and the magnitude of some exposures exceeded NIOSH limits by a factor of 10 or more. "[P]ersonal respiratory protection alone is not sufficient to adequately protect against workplace exposures." Inhalation of crystalline silica can cause incurable silicosis, lung cancer, chronic obstructive pulmonary disease, kidney

[1100] Roxana Z. Witter et al., "Occupational Exposures in the Oil and Gas Extraction Industry: State of the Science and Research Recommendations: Occupational Exposure in Oil and Gas Industry," *American Journal of Industrial Medicine* 57, no. 7 (July 2014): 847–56, https://doi.org/10.1002/ajim.22316.
[1101] R. O'Neill, "Chemicals, Dust and Deaths and the New Rush for Oil and Gas," *Hazards Magazine*, 2014, https://www.hazards.org/oil/fracking.htm#top.
[1102] Jennifer Smith Richards, "Glitch Sparks Smoky Fire at Gas Well," *The Columbus Dispatch*, June 29, 2014, https://www.dispatch.com/article/20140629/NEWS/306299873.
[1103] Laura Arenschield, "Fracking Fire Points out Failings," *The Columbus Dispatch*, August 31, 2014, https://www.dispatch.com/article/20140831/NEWS/308319916.
[1104] John Snawder et al., "Reports of Worker Fatalities during Flowback Operations," *NIOSH Science Blog* (blog), May 19, 2014, https://blogs.cdc.gov/niosh-science-blog/2014/05/19/flowback/.
[1105] Robert Iafolla, "Four Fatalities Linked to Used Fracking Fluid Exposure During 'Flowback,' NIOSH Reports," *Bloomberg BNA*, May 20, 2014, https://perma.cc/M5RY-QPZA.

disease and autoimmune diseases.[1106] Although community exposures distant from mines are possible, there are no federal or state standards for silica in ambient air.[1107]

- May 8, 2014 – A report by the AFL-CIO found that the fracking boom has made North Dakota the most dangerous state for U.S. workers—with a fatality rate five times higher than the national average—and that North Dakota's fatality rate has doubled since 2007. The AFL-CIO called North Dakota "an exceptionally dangerous and deadly place to work." U.S. Secretary of Labor Thomas E. Perez called the rising rate of workplace deaths suffered in the oil and gas sector "unacceptable."[1108]

- April 24, 2014 – A University of Texas San Antonio report commissioned by the Methodist Healthcare Ministries found that many oil and gas field workers in the Eagle Ford Shale are uninsured or underinsured and that "the most noticeable health impacts so far are work-related illnesses and injuries: heat exhaustion, dehydration, sleep deprivation, exposure to oil and gas spills and accidents." The study also noted that oil and gas production has put strain on healthcare facilities.[1109]

- April 10, 2014 –West Virginia University researcher Michael McCawley reported that some of the nation's highest rates of silicosis are in heavily drilled areas within the Northern Panhandle of West Virginia and southwestern Pennsylvania. A disease that hardens the lungs through inflammation and development of scar tissue, silicosis is entirely attributable to exposure to silica dust, a known occupational hazard at drilling and fracking operations. Two years earlier, OSHA and NIOSH issued a joint "Hazard Alert" to warn fracking workers of the health hazards of exposure to silica dust, including silicosis.[1110]

- February 25, 2014 – A year-long investigation by the *Houston Chronicle* found that fracking jobs are deadly, with high fatality rates and high rates of serious injury. Within just one year in Texas, 65 oil and gas workers died, 79 lost limbs, 82 were crushed, 92

[1106] Eric J. Esswein et al., "Occupational Exposures to Respirable Crystalline Silica During Hydraulic Fracturing," *Journal of Occupational and Environmental Hygiene* 10, no. 7 (July 2013): 347–56, https://doi.org/10.1080/15459624.2013.788352.
[1107] University of Iowa Environmental Health Sciences Research Center, "Exposure Assessment and Outreach to Engage the Public on Health Risks from Frac Sand Mining," 2012, https://web.archive.org/web/20140530144336/http://cph.uiowa.edu/ehsrc/fracsand.html.
[1108] Aimee Picchi, "The Most Dangerous U.S. State for Workers," *CBS News*, May 8, 2014, https://www.cbsnews.com/news/the-most-dangerous-us-state-for-workers/.
[1109] Y. Ghahremani, "Fractured Healthcare: Pumping Resources Back Into the Eagle Ford Shale Communities," Executive Summary (Methodist Healthcare Ministries and Center for Community and Business Research at the University of Texas San Antonio, April 2014), http://mhm.org/images/stories/pdf/Fractured%20Healthcare%20ExecSumm_FINAL.pdf.
[1110] "Gas Workers at Risk of Silica Exposure," *The Weirton Daily Times*, April 10, 2014, https://www.weirtondailytimes.com/news/local-news/2014/04/gas-workers-at-risk-of-silica-exposure/.

suffered burns and 675 broke bones. From 2007 to 2012, at least 664 U.S. workers were killed in oil and gas fields.[1111, 1112]

- December 27, 2013 – National Public Radio (NPR) reported spiking rates of fatalities related to oil and gas drilling operations, which had increased more than 100 percent since 2009. NPR noted that in the previous year, 138 workers were killed on the job, making the fatality rate among oil and gas workers nearly eight times higher than the average rate of 3.2 deaths for every 100,000 workers across all industries.[1113]

- October 30, 2012 – In a policy statement, the American Public Health Association (APHA) asserted that, high volume horizontal hydraulic fracturing (HVHF) "poses potential risks to public health and the environment, including groundwater and surface water contamination, climate change, air pollution, and worker health." The statement also noted that the public health perspective has been inadequately represented in policy processes related to HVHF.[1114] The policy statement added:

  > [H]ydraulic fracturing workers are potentially exposed to inhalation health hazards from dust containing silica. There may also be impacts on workers and communities affected by the vastly increased production and transport of sand for HVHF. Inhalation of fine dusts of respirable crystalline silica can cause silicosis. Crystalline silica has also been determined to be an occupational lung carcinogen.

- 2005 – A researcher at Stanford University examined hazards associated with oil and gas extraction from exposure to radiation and determined that inhalation of high levels of radon gas is a serious concern to workers and those living nearby. Because the boiling point of radon lies between those of propane and ethane, gaseous radon (222Rn) will concentrate in ethane and propane fractions. "Elevated Rn activity concentration values have been measured at several processing plant sites…. It is well known that the radiological impact of the oil and gas-extracting and processing industry is not negligible."[1115]

- May 9, 2003 – A New York Medical College study re-evaluated the chest X-rays of patients with exposure to silica who died from various respiratory problems and found

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[1111] Lise Olsen, "Drilling Boom, Deadly Legacy," *Houston Chronicle*, February 22, 2014, sec. Special Reports, https://www.houstonchronicle.com/news/special-reports/article/Houston-Chronicle-exclusive-Drilling-boom-5259311.php.

[1112] Steven Hsieh, "Why Are So Many Workers Dying in Oil Fields?," February 25, 2014, https://www.thenation.com/article/archive/why-are-so-many-workers-dying-oil-fields/.

[1113] Andrew Schneider and Marilyn Geewax, "On-The-Job Deaths Spiking As Oil Drilling Quickly Expands," *NPR*, December 27, 2013, sec. Business, https://www.npr.org/2013/12/27/250807226/on-the-job-deaths-spiking-as-oil-drilling-quickly-expands.

[1114] American Public Health Association, "The Environmental and Occupational Health Impacts of High-Volume Hydraulic Fracturing of Unconventional Gas Reserves," APHA, October 30, 2012, https://www.apha.org/policies-and-advocacy/public-health-policy-statements/policy-database/2014/10/02/15/37/hydraulic-fracturing.

[1115] F. Steinhäusler, "Radiological Impact on Man and the Environment from the Oil and Gas Industry: Risk Assessment for the Critical Group," in *Radiation Safety Problems in the Caspian Region*, ed. Mohammed K. Zaidi and Islam Mustafaev, vol. 41, Nato Science Series: IV: Earth and Environmental Sciences (Dordrecht: Kluwer Academic Publishers, 2005), 129–34, https://doi.org/10.1007/1-4020-2378-2_19.

that more than eight percent had undiagnosed silicosis. The study suggested that occupational lung disease may be undercounted in high-risk occupations. The authors of this study said that improved OSHA standards, with ongoing exposure monitoring and medical surveillance, would significantly improve the recognition of cases and justify more stringent preventive measures to reduce exposure. They further noted that practitioners need skills in taking an occupational exposure history. Although ten years have passed since this study was published, both recommendations have yet to be implemented.[1116]

[1116] Susan S. Goodwin et al., "Previously Undetected Silicosis in New Jersey Decedents," *American Journal of Industrial Medicine* 44, no. 3 (September 2003): 304–11, https://doi.org/10.1002/ajim.10260.

Public health effects, measured directly

By several measures, increasing evidence for fracking-related health problems has emerged across the United States and Canada.

In multiple states, studies of pregnant women in regions of intensive unconventional oil and gas extraction point to reproductive and developmental risks, including low birth weight, preterm births, and birth defects. In Oklahoma, Texas, Colorado, and Ohio, birth defects were elevated among infants whose mothers lived near drilling and fracking sites while pregnant. A 2023 study documented elevated rates of neural tube defects, spina bifida, and limb reduction defects in Ohio infants born to mothers living near drilling and fracking sites. In Texas, mothers who lived near active flare stacks while pregnant suffered higher rates of preterm birth. Also in Texas, living near fracking wells during pregnancy increased risks of preterm birth, reduced gestational age, and reduced birth weight, with Hispanic women disproportionately harmed. In California's San Joaquin Valley, women who lived with the highest exposure to oil and gas wells in early pregnancies were eight to 14 percent more likely to experience preterm births. A 2019 study in Oklahoma found evidence that drilling and fracking activities harm infant health by several measures. In British Columbia, pregnant indigenous women living near fracking sites had elevated levels of developmental toxicants, including barium and strontium, in their hair and urine.

Fracking has been linked to cancers in at least two states. In Colorado, children and young adults with leukemia were 4.3 times more likely to live in an area dense with oil and gas wells. In Pennsylvania, children living within 1.2 miles of a fracking well were 2-3 times more likely to be diagnosed with leukemia. In Pennsylvania elevated rates of bladder and thyroid cancers were found among residents living in areas of fracking activity. In southwestern Pennsylvania, dozens of children and young adults were diagnosed with a rare cancer, Ewing sarcoma, as well as other rare cancers, in a six-county area where more than 3,500 fracking wells have been drilled.

As shown by multiple studies in Pennsylvania, as the number of gas wells increase in a community, so do rates of hospitalization, and community members experience sleep disturbance, headache, throat irritation, stress/anxiety, cough, shortness of breath, sinus problems, fatigue, wheezing, and nausea. Also in Pennsylvania, hospitalizations for pneumonia among the elderly are elevated in areas of fracking activity.

Drilling and fracking operations in multiple states are variously correlated with increased rates of asthma; increased hospitalizations for pneumonia and kidney, bladder, and skin problems; high blood pressure; elevated motor vehicle fatalities; symptoms of depression and anxiety; ambulance runs and emergency room visits; and incidence of sexually transmitted diseases. An emerging body of evidence from multiple states links fracking to increased risk of death and increased rates of heart attack, ischemic heart disease, and heart failure among older residents living nearby.

Benzene levels in ambient air surrounding drilling and fracking operations are sufficient to elevate risks for future cancers in both workers and nearby residents, according to studies. Animal studies show numerous threats to fertility and reproductive success from exposure to various concentrations of oil and gas chemicals at levels representative of those found in

drinking water. At least 43 chemicals used in drilling and fracking operations are classified as known or presumed human reproductive toxicants, while 31 others are suspected human reproductive toxicants. Two dozen chemicals commonly used in fracking operations are known endocrine disruptors that can variously disrupt organ systems, lower sperm counts, and cause reproductive harm. Endocrine disrupting chemicals have also been identified in fracking wastewater. Tissue culture and animal studies show endocrine-disrupting effects in response to exposures to mixtures of fracking chemicals that reflect concentrations found in fracking wastewater.

- May 8, 2023 – Using air quality data from six government monitors, a study in northeastern British Columbia examined the relationship between particulate air pollution levels (PM10 and PM2.5) at or near the homes of 92 pregnant women and proximity to conventional oil and gas wells and wells that were fracked. The results showed that higher density and activity of nearby oil and gas wells increased gestational exposure to particulate matter among participants. Higher conventional well metrics (proximity, density, and activity) were more strongly correlated with higher PM10 estimations whereas the metrics for fracked wells were correlated with higher levels of inhalable PM2.5 but not with PM10.[1117]

- May 8, 2023 – An analysis of health impacts from air pollution due to oil and gas production in the United States in 2016 1) used information from a US EPA emissions database; 2) simulated the resulting PM2.5, NO2, and ozone air pollution as it dispersed; and 3) estimated asthma and premature mortality and related economic impacts of exposure to those pollutants at the census tract level. The research team found that air pollution from the oil and gas sector in the United States resulted in 410,000 asthma exacerbations, 2,200 new cases of childhood asthma, and 7,500 excess deaths, with a mid-point estimate of $77 billion in total health impacts. Nitrogen dioxide was the highest contributor to health impacts (37 percent) followed by ozone (35 percent) and fine particulate matter (28 percent). The impacts were highest in, but not limited to, areas with concentrated oil and gas production as they also extended to areas downwind, even into states that do not have oil and gas activity themselves.[1118]

- April 24, 2023 – Compared to other dog breeds, boxers and golden retrievers are at elevated risk for developing multicentric lymphoma, a malignancy similar to non-Hodgkin's lymphoma in humans. A recent study sought to determine whether residential radon and proximity to fracking operations are, in addition to breed, risk factors for the development of pet dog lymphoma. Fifty-six boxers and 54 golden retrievers with multicentric lymphoma were used in a case-control study. Controls without lymphoma were matched for age, breed, and sex. Counties of residence were matched to radon zones and percentage of home radon tests that exceeded the actionable radiation level of 4

[1117] Élyse Caron-Beaudoin et al., "Estimation of Exposure to Particulate Matter in Pregnant Individuals Living in an Area of Unconventional Oil and Gas Operations: Findings from the EXPERIVA Study," *Journal of Toxicology and Environmental Health, Part A* 86, no. 12 (June 18, 2023): 383–96, https://doi.org/10.1080/15287394.2023.2208594.
[1118] Buonocore et al., "Air Pollution and Health Impacts of Oil & Gas Production in the United States."

pCi/L from 2008-2017. Locations of horizontal oil and gas wells were obtained from the Enverus Database. Distances from dog homes to the closest well and well density by county were calculated for each case and control. The analysis found no significant differences in radon zones, county level radon measurements, or residential proximity to active fracking wells between dogs with and without lymphoma in either breed of dog.[1119]

- April 17, 2023 – A registry-based cohort study of 965,236 live births in Ohio from 2010-2017 examined structural birth defect risks associated with proximity of maternal residence to drilling and fracking operations. Birth defects were identified in 4653 individuals. Exposure to fracking activity was based on maternal residential proximity to active wells within 10 kilometers (6.2 miles) the density of wells, and whether or not there was a well upgradient of groundwater flow toward the maternal residence as a potential pathway of exposure to pollutants. The authors accounted for a variety of potential individual- and neighborhood-level confounders and effect modifiers. They found that children born to women who lived within 10 kilometers of fracking sites were 13 percent more likely to have any birth defect although this difference did not quite reach statistical significance. However, the risk of certain individual birth defects was significantly increased. The odds of neural tube defects were 57 percent higher, limb reduction defects 99 percent higher, and spina bifida 93 percent higher. The highest risk was associated with potential drinking water exposure from an upstream source within 10 km. The odds of hypospadias in boys was reduced by 38 percent in those whose birth home was within 10 km of a fracking site. The authors speculate that this latter finding could be due to exposure to androgenic chemicals previously identified in fracking waste water. The results corroborate some findings in other studies.[1120]

- March 6, 2023 – A study in the Marcellus Shale region of northern Pennsylvania and southern New York examined trends in hospitalizations for illnesses plausibly related to air pollution from drilling and fracking operations among older people as fracking activity rapidly increased in Pennsylvania after 2009. Using 2002-2015 Medicare claims, the authors took advantage of the stark difference in fracking activity between Pennsylvania, where the practice became widespread beginning in 2008, and New York, where the practice was and remains banned. The team selected three northern Pennsylvania counties to serve as the exposed areas and two unexposed neighboring regions in New York as controls. For each region, from 2002 to 2015, they identified the numbers and trends for hospitalization with acute myocardial infarction (heart attack), chronic obstructive pulmonary disease, bronchiectasis, heart failure, ischemic heart disease, and stroke among adults aged ≥65 years. The authors examined the differences in hospitalization rates for these conditions among the three regions before fracking began in Pennsylvania and then followed the numbers and trends in the following years with increasing exposure to fracking activities. They found that from 2002-2008 the rates

[1119] Ashleigh Tindle and Lauren Trepanier, "Radon and Fracking Exposures and Lymphoma Risk in a Canine Model of Non-Hodgkin Lymphoma," *Journal of Clinical and Translational Science* 7, no. s1 (April 2023): 142–142, https://doi.org/10.1017/cts.2023.502.
[1120] Casey Gaughan et al., "Residential Proximity to Unconventional Oil and Gas Development and Birth Defects in Ohio," *Environmental Research*, April 2023, 115937, https://doi.org/10.1016/j.envres.2023.115937.

of hospitalizations for these illnesses and their trends were similar in the Pennsylvania and New York regions. But soon after 2009, the trends began to diverge. In New York, the trends for heart attack and heart failure continued downward, while they began to increase in Pennsylvania where fracking intensity increased. For heart attacks, the association between hospitalization rates and fracking grew consistently larger between 2012 and 2015 in Pennsylvania. In 2015 alone, Pennsylvania counties had an additional 11.8, 21.6, and 20.4 hospitalizations for acute myocardial infarction, heart failure, and ischemic heart disease, respectively, per 1000 Medicare beneficiaries than would have been expected without fracking. The team did not find an association between fracking and chronic obstructive pulmonary disease or stroke.[1121]

- February 1, 2023 – Researchers in Broomfield, Colorado studied health symptoms in residents where oil and gas fracking operations had rapidly developed close to residential neighborhoods. A survey of 3,993 randomly selected households investigated any association between living near wells and frequency of a variety of health-related symptoms. Homes were within 1 mile of well pads, within 1–2 miles, or more than 2 miles away. Response rates to the survey for the three distance bands were similar. During the survey, 30 wells were in the production phase, 21 in the pre-production phase, and 33 had no activity. The research team found no differences in unadjusted analysis of self-reported health symptoms by setback distance. However, after adjusting for a number of individual and family-related variables, symptoms trended higher as the distance to the wells decreased. This association was particularly apparent for upper respiratory, lower respiratory, and gastrointestinal symptoms. There were no differences in reports of mental health or neurological symptoms.[1122]

- December 23, 2022 – A study of exposure to trace elements, many of which are known to be released in fracking wastewater, was undertaken in 85 pregnant women living in northeastern British Columbia where fracking development has rapidly increased in the past 15 years. The researchers found elevated urinary levels of barium, cobalt, copper, manganese, selenium, strontium, and vanadium when compared to reference populations in Canada or the United States. These findings suggest that people living near fracking wells could be exposed to elevated levels of contaminants, conceivably introduced into ground- or surface-water by hydraulic fracturing, and raise concerns about potential impacts in the developing fetus.[1123]

- December 2, 2022 – A Texas statewide population-based cohort study of birth defects, identified through two different birth defect registries, examined associations between

[1121] Kevin S Trickey, Zihan Chen, and Prachi Sanghavi, "Hospitalisations for Cardiovascular and Respiratory Disease among Older Adults Living near Unconventional Natural Gas Development: A Difference-in-Differences Analysis," *The Lancet Planetary Health* 7, no. 3 (March 2023): e187–96, https://doi.org/10.1016/S2542-5196(23)00009-8.
[1122] Meagan L. Weisner et al., "Health Symptoms and Proximity to Active Multi-Well Unconventional Oil and Gas Development Sites in the City and County of Broomfield, Colorado," *International Journal of Environmental Research and Public Health* 20, no. 3 (February 1, 2023): 2634, https://doi.org/10.3390/ijerph20032634.
[1123] Lucie Claustre et al., "Assessing Gestational Exposure to Trace Elements in an Area of Unconventional Oil and Gas Activity: Comparison with Reference Populations and Evaluation of Variability," *Journal of Exposure Science & Environmental Epidemiology*, December 23, 2022, https://doi.org/10.1038/s41370-022-00508-8.

multiple exposure measures of oil and gas extraction and odds of congenital anomalies. Birth outcomes of mothers who lived within 5 kilometers (3.1 miles) of an oil or gas well, combined with intensity of activity at the well(s), were compared to birth outcomes in an otherwise similar group. The study found a 25 percent increased risk of having a child with any birth defect, when using proximity to well site, well site count, gas production, and produced water as exposure measures. For cardiac and circulatory anomalies, the association was particularly robust and consistent for all measures of exposure. Associations were smaller and less consistent for oil production. The authors hypothesized that the agents responsible for this association may include hazardous fluids associated with various steps in the production process; pollutants from diesel truck traffic; flaring; and naturally occurring radioactive material that is pumped from the ground.[1124]

- October 17, 2022 – A population-based, case control study in Germany examined the relationship between residential proximity to an oil or gas well and the likelihood of being diagnosed with a hematologic malignancy in adulthood. The study included 3,978 cases and 15,912 similar controls without malignancy. Residential proximity to oil or gas wells at the time of diagnosis was used as the exposure measure. Proximity to main roadways and agricultural land were considered potential confounders. Cases were not contacted so individual smoking history, occupation, and nutrition were unknown. The study found no association between residential proximity to oil or gas wells for all hematologic malignancies. When stratified by subtype, the odds of acute myelogenous leukemia was 34 percent higher, although this difference was not statistically significant. When stratifying by gender, the odds of malignancy was 50 percent higher in women living near wells than in controls. When the analysis was limited to gas production sites only, the odds of hematologic malignancy were 50 percent higher in people living within one kilometer (.62 miles) of a well.[1125]

- October 3, 2022 – Most of the evidence of negative impacts of natural gas development on infant health comes from high-producing states in the United States. To expand the generalizability of the findings, a cross-sectional study examined associations between proximity to natural gas development and county-level birth outcomes, overall and by race/ethnicity, in all states where gas drilling takes place. The study included 33,849,409 births from the 28 states with any natural gas extraction—conventional and/or unconventional—from 2005 to 2018. The analysis examined birth outcomes associated with the distance between the population-weighted center in each county and the nearest well, combined with its production levels. Overall, prenatal proximity to natural gas extraction activity was associated with increased adverse birth outcomes. A 10 percent increase in gas production in a county was associated with a small decrease in mean birth weight (1.48 grams). The association was larger in women of color—a 10 percent

[1124] Mary D. Willis, Susan E. Carozza, and Perry Hystad, "Congenital Anomalies Associated with Oil and Gas Development and Resource Extraction: A Population-Based Retrospective Cohort Study in Texas," *Journal of Exposure Science & Environmental Epidemiology* 33, no. 1 (January 2023): 84–93, https://doi.org/10.1038/s41370-022-00505-x.

[1125] Felix Forster et al., "Residential Proximity to Oil and Gas Production Sites and Hematologic Malignancies: A Case-control Study," *American Journal of Industrial Medicine* 65, no. 12 (December 2022): 985–93, https://doi.org/10.1002/ajim.23434.

increase in gas production decreased birth weight for infants born to Black women by 10.19 grams and Asian women by 2.76 grams. Increases in gas production were associated with slightly increased gestational age, particularly for infants born to Black women, a finding inconsistent with prior literature showing gas production associated with an increased risk of preterm birth. This study used county-level data for both birth outcomes and distance from each well and is, therefore, not as granular as others that are able to examine the association between individual birth outcomes and residential distance from the nearest well.[1126]

- August 17, 2022 – A well-designed study in Pennsylvania found that children whose birth residence was within 2 kilometers (1.2 miles) of a fracking site were 2-3 times more likely to be diagnosed with acute lymphoblastic leukemia between ages 2-7 years than otherwise similar children who were not living near fracking sites. While those living within two kilometers faced the highest risk, leukemia levels among children were elevated as much as 10 kilometers (6.2 miles) from a well, raising questions about safe setback distances. The study included 405 children with leukemia identified through the state cancer registry and considered prenatal, perinatal, and postnatal time periods as potential windows of susceptibility to fracking-related exposures. Similarly, increased odds of acute lymphoblastic leukemia were also seen when fracking wells were located upstream and groundwater flow toward the residence was considered as a potential pathway of exposure. These findings suggest that contaminated drinking water could be an important risk factor.[1127]

- April 4, 2022 – A 2022 Canadian study in rural Alberta found that babies born to mothers living within 6.2 miles (10 kilometers) of one or more fracking wells had increased incidence of low birth weight, premature birth, and major congenital abnormalities. This study included nearly 35,000 pregnancies over a six-year period, 2013-2018.[1128]

- January 30, 2022 – A research team working in Pennsylvania found "consistent and robust evidence that drilling shale gas wells negatively impacts both drinking water and quality of infant health." Using exact geographic locations of mothers' residences, gas wells, and public drinking water sources—as well as dates of infant births, timing of drilling and fracking activities, and water measurements—the team showed that shale gas operations near mothers' homes raised levels of contaminants in drinking water and raised the risk for preterm birth and low birthweight.[1129]

[1126] Hailee Schuele et al., "Associations between Proximity to Gas Production Activity in Counties and Birth Outcomes across the US," *Preventive Medicine Reports*, October 2022, 102007, https://doi.org/10.1016/j.pmedr.2022.102007.
[1127] Cassandra J. Clark et al., "Unconventional Oil and Gas Development Exposure and Risk of Childhood Acute Lymphoblastic Leukemia: A Case–Control Study in Pennsylvania, 2009–2017," *Environmental Health Perspectives* 130, no. 8 (August 2022): 087001, https://doi.org/10.1289/EHP11092.
[1128] Zoe F. Cairncross et al., "Association Between Residential Proximity to Hydraulic Fracturing Sites and Adverse Birth Outcomes," *JAMA Pediatrics*, April 4, 2022, https://doi.org/10.1001/jamapediatrics.2022.0306.
[1129] Elaine L. Hill and Lala Ma, "Drinking Water, Fracking, and Infant Health," *Journal of Health Economics*, 2022, 102595, https://doi.org/10.1016/j.jhealeco.2022.102595.

- January 22, 2022 – Using data gathered from more than 15 million Medicare recipients and records from more than 2.5 million gas and oil wells, a Harvard University research team found that older citizens (65 years old and up) living near wells were at higher risk for dying earlier than those who lived in areas without fracking. Furthermore, those living downwind from fracking wells were more likely to suffer premature death than those upwind.[1130]

- January 20, 2022 – A research team that included First Nations investigators found that the air inside the homes of 85 pregnant women living close to fracking operations in British Columbia had higher levels of volatile organic compounds, including chloroform and acetone, compared with the general population. Further, greater well density was linked to increased exposure. Proximity to fracking operations was inconsistently linked to preterm birth and smaller birthweights.[1131]

- January 6, 2022 – A retrospective cohort study in north central West Virginia documented a rise in cases of a rare autoimmune disease (ANCA-associated vasculitis) in areas of fracking activity and during a period of time in which gas extraction through fracking was increasing. Previous research demonstrates that environmental exposure is implicated in the pathophysiology of this disease.[1132]

- December 13, 2021 – A study led by Oregon State University researchers of more than 3 million pregnant women in Texas showed that living near an active oil or gas well increased the risks for both gestation hypertension (high blood pressure) and eclampsia (onset of seizures or coma during pregnancy or childbirth). "Among pregnant women who reside within 1 km of at least one oil or gas drilling site, we find 5% increased odds of gestational hypertension and 26% increased odds of eclampsia."[1133]

- April 17, 2021 – A Stanford, Berkeley, and Columbia medical and public health science team identified a link between fracking-related air pollution and migraine headache as part of a study of long-term exposure to nitrogen dioxide (NO_2) and methane from industrial "super-emitters." One of two categories of methane super-emitters in the study included power plants, refineries, oil and gas production sites, wastewater treatment facilities, and oil and gas distribution infrastructure, such as compressors stations and distribution lines. The study also found that living within ten kilometers of any active oil and gas well was associated with increased frequency of outpatient neurologist visits, frequency of migraine-specific urgent care visits, and odds of at least one migraine-

[1130] Longxiang Li et al., "Exposure to Unconventional Oil and Gas Development and All-Cause Mortality in Medicare Beneficiaries," *Nature Energy*, 2022, https://doi.org/10.1038/s41560-021-00970-y.
[1131] Élyse Caron-Beaudoin et al., "Volatile Organic Compounds (VOCs) in Indoor Air and Tap Water Samples in Residences of Pregnant Women Living in an Area of Unconventional Natural Gas Operations: Findings from the EXPERIVA Study," *Science of The Total Environment* 805 (2022): 150242, https://doi.org/10.1016/j.scitotenv.2021.150242.
[1132] Devan Makati et al., "Prevalence of ANCA-Associated Vasculitis amid Natural Gas Drilling Sites in West Virginia," *Journal of Nephrology*, 2022, https://doi.org/10.1007/s40620-021-01243-3.
[1133] Mary D Willis et al., "Associations between Residential Proximity to Oil and Gas Extraction and Hypertensive Conditions during Pregnancy: A Difference-in-Differences Analysis in Texas, 1996–2009," *International Journal of Epidemiology*, 2021, dyab246, https://doi.org/10.1093/ije/dyab246.

specific emergency room visit per person-year of follow-up. (This measurement takes into account the number of people in the study and the amount of time each person is in the study.) This study, the first to uncover a potential link between exposure to methane super-emitters and migraine, used a Northern California electronic health record data set of nearly 90,000 migraine cases between 2014 and 2018 and compared them to matched controls. It also documented a link between annual average NO_2 and fine particulate matter exposure and migraine headache severity. In addition to emitted air pollutants as risk factors, authors also noted that super-emitters such as oil and gas wells produce noise pollution, and both noise and odors are consistently linked with migraine headache.[1134]

- March 31, 2021 – Fracking operations shorten lifespans and otherwise represent significant risks to the public health in Oklahoma, according to a unique study using a comprehensive health profile of the population across 76 counties, over twenty years (1998–2017). This research demonstrated that an increase in the number of fracking wells in a county has a detrimental effect on life expectancy. On average, a one percent increase in the number of fracking wells in a county leads to a 4.2 percent reduction in life expectancy. Researchers found analogous trends with other health outcomes. A one percent increase in the number of fracking wells led to a 7.9 percent increase in cancer incidence, a 7.3 percent increase in cardiac diseases, and a 5.9 percent increase in respiratory diseases. Researchers recommended that policymakers "dismiss fracking as a viable option and promote energy technologies that can have less harmful effects on health," and that "the public health risks results presented in this study can be beyond any effective regulation in which case prevention becomes a major policy option."[1135]

- March 29, 2021 – Living near urban oil drilling sites in South Los Angeles was linked with reduced lung function among residents in a community-driven epidemiological study led by a University of Southern California and Occidental College team. The researchers obtained 747 valid spirometry tests of residents living less than 1000 meters from two oil well sites (one active, one idle) in the Las Cienagas oil field, measuring FEV1 (forced expiratory volume in the first second of exhalation) and FVC (forced vital capacity). These are measures of lung capacity and lung strength, and they are both predictors of serious health problems, as well as of early death. The study found that living fewer than 200 meters from oil operations was associated with on average −112 mL lower FEV1 and −128 mL lower FVC compared to those living more than 200 meters from the sites. Further, residents living downwind and less than 200 meters from oil operations had on average −414 mL lower FEV1 and −400 mL lower FVC, compared to residents living upwind and more than 200 meters away from the wells. Researchers adjusted for factors including but not limited to proximity to freeway, smoking status, and asthma status. Researchers wrote that the impacts on lung function they found among non-asthmatic participants indicated that the drilling "may have adverse effects on

[1134] Holly Elser et al., "Air Pollution, Methane Super-Emitters, and Oil and Gas Wells in Northern California: The Relationship with Migraine Headache Prevalence and Exacerbation," *Environmental Health* 20, no. 45 (2021), https://doi.org/10.1186/s12940-021-00727-w.
[1135] Nicholas Apergis, Ghulam Mustafa, and Sayantan Ghosh Dastidar, "An Analysis of the Impact of Unconventional Oil and Gas Activities on Public Health: New Evidence Across Oklahoma Counties," *Energy Economics* 97 (2021), https://doi.org/10.1016/j.eneco.2021.105223.

otherwise healthy people." A second part of the study, which included the collection of self-reported acute health symptoms, indicates that residents living near the active drilling site had a greater prevalence of symptoms, including wheezing, sore throat, chest tightness, dizziness, and eye or nose irritation compared to residents near the idle well site. Authors said that their urban findings are similar to those found in studies of rural residents near gas fracking sites. The area where this study was situated "is among the top 10% most disproportionately-environmentally burdened in the state."[1136] In media coverage addressing a failed state legislative effort to enact 2,500-foot buffer between drilling sites and schools, home and playgrounds, lead study author Jill Johnston of USC said that the link between worse lung function and the drilling sites found in the communities where her research took place "shows this is a real public health hazard."[1137]

- March 1, 2021 – High levels of fracking-related chemicals were found in the bodies of residents living in five southwestern Pennsylvania households located near fracking operations. None of the households included smokers and each included at least one child.[1138] An investigative journalist and her colleagues with *Environmental Health News*, in consultation with scientific advisors, collected 59 urine samples, 39 air samples, and 13 water samples, which were subsequently analyzed in a University of Missouri lab. (Raw data by family and compound is available in the referenced link.)[1139] This pilot study was the first to document the body burden of fracking-related chemicals in Pennsylvanians and represents one of very few biomonitoring studies of these chemicals. Findings included very high levels of chemicals known to be released from fracking sites in the bodies of a family living within 1.5 miles of six wells. This family had benzene, toluene, naphthalene, and 15 other chemicals in their urine samples. These chemicals are all known to have negative health impacts, including reproductive harm and cancer risk. A biomarker for toluene in a 9-year-old child in the family was 91 times as high as that of the average American. Each of the family's sample levels exceeded the U.S. 95th percentile for mandelic acid, a biomarker of ethylbenzene and styrene, and more than half of the family's samples exceeded the U.S. 95th percentile for phenylglyoxylic acid, another biomarker for ethylbenzene and styrene, as well as for trans, transmuconic acid, a biomarker for benzene. These U.S. percentiles for comparison were drawn from the Centers for Disease Control and Prevention's National Health and Nutrition Examination Survey. Overall, families in the investigation that lived closer to fracking operations had higher levels of several chemicals than those living further away. Highlighting this investigation, 35 members of the Pennsylvania House and Senate responded by publicly

[1136] Jill E. Johnston et al., "Respiratory Health, Pulmonary Function and Local Engagement in Urban Communities Near Oil Development," *Environmental Research* 197 (2021), https://doi.org/10.1016/j.envres.2021.111088.
[1137] Janet Wilson, "California Bill to Ban Fracking Dies, But Other Oil Regulation Measures Win Votes," *Desert Sun*, April 13, 2021, https://www.desertsun.com/story/news/environment/2021/04/13/california-bill-ban-fracking-dies-senate-committee-buffer-zones/7212190002/.
[1138] Kristina Marusic and EHN Staff, "Fractured: The Body Burden of Living Near Fracking," *Environmental Health News*, March 1, 2021, https://www.ehn.org/fractured-series-on-fracking-pollution-2650624600/fractured-fracking.
[1139] Charles Minshew, "EHN- A Family's Chemical Exposure," January 4, 2021, https://public.tableau.com/app/profile/charles.minshew2414/viz/EHN-AFamilysChemicalExposure/FamilyDashboard.

requesting that the Pennsylvania governor "direct adequate funding to thoroughly study the full and complete health impacts of fracking."[1140]

- February 11, 2021 – An investigation of fracking and heart attack risk found that long-term exposure to fracking operations was associated with increased acute myocardial infarction (AMI) hospitalization rates and increased AMI death rates in a study that compared Pennsylvania and New York counties atop the Marcellus Shale, from 2005–2014. This study design was made possible by the natural experiment created by New York's statewide ban on fracking and the opposing decision by Pennsylvania to pursue shale gas extraction enthusiastically. Specifically, one hundred cumulative fracking wells drilled in a county was linked with 1.4–2.8 percent increases in AMI hospitalizations, depending on age and sex, and with a 5.4 percent increase in AMI deaths among men age 45 to 54. Of these findings, the authors wrote, "To put this into perspective, three Pennsylvania counties – Bradford, Washington, and Susquehanna… – each had over a thousand unconventional wells by the end of 2014, with hundreds more drilled since then. Not coincidentally, these three counties are the ones with the most individual cardiovascular health complaints submitted to the Pennsylvania Department of Health between 2011 and February 2018." Noting that their findings are consistent with a few previous studies on fracking and cardiovascular hospitalizations, the authors concluded that these results "suggest that bans on hydraulic fracturing can be protective for public health."[1141]

- December 15, 2020 – A major study published in the *Journal of the American College of Cardiology* documented a link between fracking and heart failure. Using a case-control analysis and data on more than 12,000 patients from health records in an integrated health system across the state of Pennsylvania, researchers from Johns Hopkins University found that heart failure patients living near fracking sites were significantly more likely to become hospitalized. The results showed strong associations between fracking activity and two types of heart failure, with older heart-failure patients particularly vulnerable to adverse health impacts from fracking activity. Heart failure patients exposed to the highest intensity of fracking activity were more likely to be hospitalized for heart failure compared with those who were in the lowest intensity of exposure.[1142] "These associations can be attributed to the environmental impacts of fracking, including air pollution, water contamination, and noise, traffic, and community impacts" with possible underlying mechanisms including systemic inflammation, autonomic dysfunction,

[1140] Sara Innamorato, "Pennsylvania House and Senate Elected Officials Strongly Urge Governor Wolf to Investigate Serious Health Impacts Associated with Fracking" (PA House of Reps., March 18, 2021), https://www.pahouse.com/Innamorato/InTheNews/NewsRelease/?id=118917.
[1141] Alina Denham et al., "Acute Myocardial Infarction Associated with Unconventional Natural Gas Development: A Natural Experiment," *Environmental Research* 195 (2021), https://doi.org/10.1016/j.envres.2021.110872.
[1142] Tara P. McAlexander et al., "Unconventional Natural Gas Development and Hospitalization for Heart Failure in Pennsylvania," *Journal of the American College of Cardiology* 76, no. 24 (2020): 2862–74, https://doi.org/10.1016/j.jacc.2020.10.023.

prothrombotic pathways, and epigenomic changes, all of which are known to contribute to heart failure.[1143]

- November 24, 2020 – Pregnant women living near fracking sites in Texas had increased risk for serious birth defects in their infants, including neurological defects, heart defects, and gastroschisis, according to a case-control study that compared nearly 53,000 cases with birth defects to 642,399 controls, from 1999 to 2011. Gastroschisis is an abnormality of the abdominal wall that allows the baby's intestines (and sometimes other organs) to protrude outside of the body. Specifically, researchers found links between maternal addresses within one kilometer (0.6 miles) of the highest fracking site density and the following birth defects: anencephaly, spina bifida, gastroschisis (for births from older mothers), aortic valve stenosis, hypoplastic left heart syndrome, and pulmonary valve atresia or stenosis. Based on these geographic patterns, the research team suggests that neural tube defects may be linked to "acute, frequent, and concentrated airborne exposures from high-intensity" fracking activities. Almost always fatal, anencephaly is a neural tube defect in which a large part of the skull is absent along with parts of the brain; spina bifida is a neural tube condition that affects the spine and spinal cord and can create paralysis. In addition, researchers found significant increased risk of congenital heart defects at all three maternal address distances to fracking that the study analyzed, radii of of 1, 3, and 7.5 kilometers. Because this type of risk was consistent across the three different distances, the researchers suggest that exposures linked with congenital heart defects might be due to groundwater contamination of a public supply serving an extended geographic area. An additional component of the study showed an increased risk for ventricular septal defects and atrial septal defects over time, possibly reflecting the increasing fracked well numbers around the state. Researchers wrote that their study supports previous research investigating fracking and birth defects, and that their analyses suggest that vulnerable populations near fracking sites, particularly minority and lower socioeconomic status (terms used by the authors) mothers, may be at greater risk for birth defects.[1144]

- November 20, 2020 – A study appearing in the journal *Public Health Nursing* found a correlation between oil development and gonorrhea rates in North Dakota between the fracking boom years of 2002 to 2016. Previous research has documented the link between sexually transmitted infections (STIs) and fracking in Ohio and Pennsylvania, but, heretofore, North Dakota has been far less studied. A second part of the study evaluated the state's public health infrastructure and ability to respond to the STI-related needs of North Dakota's growing transient population during that same period. Researchers found wide-ranging deficits, including lack of primary care services, limited STI testing, limited funding, large service areas, and lack of confidentiality. The authors recommended expanding the role of public health nurses in North Dakota to implement STI screening,

[1143] Barrak Alahmad and Haitham Khraishah, "Unconventional Natural Gas Development and Heart Failure: Accumulating Epidemiological Evidence," *Journal of the American College of Cardiology* 76, no. 24 (2020): 2875–77, https://doi.org/10.1016/j.jacc.2020.10.040.
[1144] Ian W. Tang, Peter H. Langlois, and Verónica M. Vieira, "Birth Defects and Unconventional Natural Gas Developments in Texas, 1999–2011," *Environmental Research* 194 (2021): 110511, https://doi.org/10.1016/j.envres.2020.110511.

which would allow for comprehensive reporting and treatment. This study documented increased STI rates across the state during the fracking boom without evidence of greater infection rates in oil-producing counties than in others. Authors posit this is due to factors unique to North Dakota such as the public health infrastructure deficits mentioned above, as well as factors such as workers traveling to oil-producing counties for work and returning home to more urban areas, where STI rates are documented to be higher.[1145]

- September 30, 2020 – In a study that corroborates earlier findings from Pennsylvania on an association between asthma and fracking activities, researchers reported links between childhood asthma hospitalizations and both unconventional and conventional gas development in Texas. The team used a database of inpatient hospitalizations between 2000 and 2010, and zip code-level information including gas drilling type, production volumes, and gas-flaring volumes. They found increasing production volumes tracked with increased childhood asthma hospitalizations, following an exposure-response pattern. This study found inconsistent associations with gas flaring, but the authors noted that the available data on flaring was only "reasonable for inferring if flaring occurred, but the relative magnitude of flaring is more difficult to determine," and that flaring activity peaked in 2018 (beyond the years covered in the study). Hence, this study may have underestimated the impact of exposure to flaring. This study also has important environmental justice dimensions. Researchers found communities with lower income and more non-White population had higher odds of childhood asthma hospitalizations. Authors noted, "the U.S. Department of Energy is specifically instructed to monitor the impact of the energy sector on these communities, and the current study provides evidence that drilling exposures seem to be inequitably distributed in Texas."[1146]

- August 18, 2020 – A modeling study that used a retrospective analysis and a novel method to quantify exposures from fracking wells in southwest Pennsylvania found that respiratory, neurological, and muscular symptoms tracked with cumulative well density around residential areas. The results suggest that living in proximity to wells may be associated with health symptoms. These findings also indicate that an estimation of exposure that relies on proximity to fracking wells alone may be simplistic, particularly in communities with increasing density of wells. The authors suggest that future research should examine how the aggregation of exposures from fracking wells and potency of exposures at the residence levels affects health.[1147]

- July 15, 2020 – Maternal proximity to flaring, the open combustion of natural gas, was linked to a fifty percent increased chance of preterm birth in a study of 23,487 birth

[1145] Andrea L. Huseth-Zosel et al., "Associations Between Oil Development and Sexually Transmitted Infections: Public Health Nurse Perspectives," *Public Health Nursing* 38, no. 1 (2021): 4–12, https://doi.org/10.1111/phn.12836.
[1146] Mary Willis et al., "Natural Gas Development, Flaring Practices and Paediatric Asthma Hospitalizations in Texas," *International Journal of Epidemiology* 49, no. 6 (2020): 1883–96, https://doi.org/10.1093/ije/dyaa115.
[1147] Hannah N. Blinn et al., "Exposure Assessment of Adults Living near Unconventional Oil and Natural Gas Development and Reported Health Symptoms in Southwest Pennsylvania, USA," *PLoS One* 15, no. 8 (2020): e0237325, https://doi.org/10.1371/journal.pone.0237325.

records from 2012 to 2015 in the Eagle Ford Shale of south Texas.[1148] The USC and UCLA researchers used satellite data on flaring activity to determine how much flaring took place during the pregnancies, within five kilometers of the maternal residence. They defined a "high" amount as ten or more nightly flare events within three miles of the residence. The researchers statistically adjusted for other known pregnancy risks, also including numbers of oil and gas wells in their analyses, "suggesting the effects of flaring on the length of gestation are independent of other potential exposures related to oil and gas wells." In addition to the flaring exposure effects, the study also found that living within five kilometers of oil and gas wells was independently linked to a higher chance of preterm birth, reduced gestational age, and reduced birth weight. In this first study to address the human health effects of flaring, offspring of Hispanic women were especially impacted. The researchers stated that this finding suggests theirs was "the first study to document greater health impacts associated with [oil and gas development] among women of color." Researchers expressed environmental justice concerns, given that approximately 50 percent of residents living within five kilometers of an oil or gas well are people of color. In an interview with *Environmental Health News,* a lead author said, "Historically, much of the waste disposal in the U.S. is concentrated in communities of color… One theory is that we're seeing the same pattern with flaring, which is essentially another type of waste disposal."[1149] Authors called for measures to protect the health of infants, including reducing reliance on fossil fuels.

- July 10, 2020 – Researchers found inconsistent links between density/proximity to fracking wells during pregnancy and lower birthweight, and limited evidence of a link with increased risk of preterm birth, in the first epidemiological study of its kind in Northeastern British Columbia. They analyzed over 6,000 births at one hospital between December 30, 2006 and December 29, 2016, and the density and proximity of fracking wells in areas of 2.5, 5, and 10 kilometers (1.5, 3.1, and 6.2 miles) around the pregnant women's postal codes. Precise maternal addresses were not available to the researchers. The study found increased risk of preterm birth among women in the second quartile of well density/proximity of the 2.5-kilometer category. The researchers noted that a key limitation was their relatively small sample size compared to other epidemiological studies of fracking and birth outcomes, "which can decrease precision in our effect estimates."[1150]

- June 5, 2020 – San Joaquin Valley, California women who lived with the highest exposure to oil and gas wells in the first and second trimesters of their pregnancies were eight to 14 percent more likely to experience a spontaneous preterm birth at 20 to 31

[1148] Lara J. Cushing et al., "Flaring from Unconventional Oil and Gas Development and Birth Outcomes in the Eagle Ford Shale in South Texas," *Environmental Health Perspectives* 128, no. 7 (July 2020): 077003, https://doi.org/10.1289/EHP6394.
[1149] Kristina Marusic, "Babies Born Near Gas Flaring Are 50 Percent More Likely To Be Premature," *The Daily Climate*, July 15, 2020, https://www.dailyclimate.org/fracking-preterm-births--2646412309/particle-4.
[1150] Élyse Caron-Beaudoin et al., "Density and Proximity to Hydraulic Fracturing Wells and Birth Outcomes in Northeastern British Columbia, Canada," *Journal of Exposure Science & Environmental Epidemiology* 31, no. 1 (2021): 53–61, https://doi.org/10.1038/s41370-020-0245-z.

weeks' gestation, according to Stanford University research.[1151] The women studied did not have maternal comorbidities for preterm birth, such as gestational or pregestational diabetes, gestational hypertension, and preeclampsia/eclampsia. The researchers analyzed data on 27,913 preterm births and 197,461 comparison term births between 1998 and 2011, with data for 83,559 wells in preproduction or production during the same period, establishing four "exposure quantiles" (no exposure up to the highest exposure). Most of these California wells were drilled using conventional methods. The harmful birth impacts of living near oil and gas wells were strongest among the women who were Hispanic, Black, or had fewer than 12 years of education. In a secondary analysis, the researchers determined that exposure to wells in preproduction was associated with higher concentrations of particulate matter. Though they found a link between preterm birth and exposure to both new and active wells, researchers were not able to determine whether exposure to wells in either stage presents more risk.

- June 3, 2020 – Living near active oil and gas wells during pregnancy was found to increase the risk of low-birthweight babies, specifically in rural areas, according to the largest study of its kind and the first in California.[1152] The UC Berkeley-led study found that pregnant people who lived within 0.62 miles (one kilometer) of the highest producing oil and gas wells (more than 100 barrels of oil or the natural gas equivalent) were 40 percent more likely to have low birth weight babies. Further, among full-term births from mothers with the same proximity to highest producing wells, 20 percent were more likely to have babies who were small for their gestational age. The researchers used nearly 3 million birth certificates of babies born to mothers living within ten kilometers of at least one active or inactive well from 2006 to 2015, in the Sacramento Valley, San Joaquin Valley, South Central Coast and Los Angeles Basin. Mothers in the study group exposed to high production volume had an average of 160 inactive wells and 32 active wells within one kilometer. For urban areas, the group within one kilometer of high production volume, compared to no exposure, showed increased odds of small for gestational age babies. They also found modest impacts on birth outcomes linked to proximity to inactive wells, and suggested a possible role of emissions from inactive wells such as methane and residual off-gassing of BTEX contaminants. Certain factors that the researchers could not take into account, such as maternal occupation, housing quality, and indoor air quality, may have contributed to differences between findings in rural and urban populations. Though the study could not account for maternal changes of residence during pregnancy, researchers suggested that because they saw similar effects across trimesters, "any bias resulting from maternal residential and occupational mobility is likely non- differential across trimesters." Authors concluded that prenatal exposure to active oil and gas production using the range of conventional and unconventional techniques employed in California was associated with adverse birth outcomes. Co-author Kathy Tran said to the *Guardian*, "Because researchers don't have direct access to

[1151] David J. X. Gonzalez et al., "Oil and Gas Production and Spontaneous Preterm Birth in the San Joaquin Valley, CA: A Case–Control Study," *Environmental Epidemiology* 4, no. 4 (August 2020): e099, https://doi.org/10.1097/EE9.0000000000000099.
[1152] Kathy V. Tran et al., "Residential Proximity to Oil and Gas Development and Birth Outcomes in California: A Retrospective Cohort Study of 2006–2015 Births," *Environmental Health Perspectives* 128, no. 6 (June 2020): 067001, https://doi.org/10.1289/EHP5842.

the actual oil and gas sites, it's hard to get a good estimate of what people actually experience… The more in-depth exposure assessment we can get, the more we can really understand why we are seeing the [birth outcome] effects that we see."[1153]

- May 27, 2020 – A fracking chemical called Genapol-X100 can interfere with normal activity of the male hormones, according to research performed by University of California toxicologists.[1154] The scientists ranked 60 fracking chemicals used in California, based on their potential to interfere with androgens' ability to bind with living human cells. Their assessment found five fracking chemicals with the highest potential to interfere with this process, subsequently identifying Genapol-X100 as a significant androgen disruptor. In their discussion they said that exposure to these chemicals "can affect the normal physiology of androgen pathways such as male reproduction health," and have other related adverse outcomes. Previous research in 2016 reported that Genapol-X100 was used as a chemical constituent in well stimulation treatments more than 500 times, but authors stated that the levels of this chemical in humans and wildlife is not well documented. They wrote that their findings demonstrate this chemical "may pose significant environmental and health risks as it noncompetitively inhibits [human androgen receptor] and alters the expression of androgenic genes at relatively low concentrations."

- May 8, 2020 – A water disinfection byproduct (DBP), monohalogenated iodoacetic acid (IAA), disrupted each major level of the female reproductive axis in an animal model experiment by University of Illinois scientists.[1155] DPBs arise when chemicals used to for water decontamination combine with organic material and they have been linked to reproductive disfunction. IAA forms when iodide reacts with a disinfectant. The researchers noted, "not only is iodide widely present in the water supply, especially in coastal communities and those near fracking sites, but IAA has been found to be one of the most cyto- and genotoxic DBPs." Their study linked exposure to IAA to disruptive expressions of key endocrine genes related to reproductive function.

- March 4, 2020 – Exposures to a mixture of fracking chemicals commonly found in wastewater caused effects on diverse physiological systems though hormone disruption, according to a set of coordinated studies carried out collaboratively by an interdisciplinary team.[1156] (See also July 25, 2019 and May 22, 2019 entries below.) These studies, conducted in laboratory animals and human tissue culture cells, used four

[1153] Nina Lakhani, "Living near Oil and Gas Wells Linked to Low Birthweight in Babies," *The Guardian*, June 3, 2020, sec. Environment, http://www.theguardian.com/environment/2020/jun/03/living-near-oil-and-gas-wells-linked-to-low-birthweight-in-babies.
[1154] Phum Tachachartvanich et al., "Structure-Based Discovery of the Endocrine Disrupting Effects of Hydraulic Fracturing Chemicals as Novel Androgen Receptor Antagonists," *Chemosphere* 257 (October 2020): 127178, https://doi.org/10.1016/j.chemosphere.2020.127178.
[1155] Rachel Gonzalez et al., "Adult Exposure to Iodoacetic Acid Leads to Abnormal Expression of Key Genes Related to Hypothalamic and Pituitary Control of Reproductive Function," *Journal of the Endocrine Society* 4, no. Supplement_1 (May 8, 2020): SUN-241, https://doi.org/10.1210/jendso/bvaa046.1083.
[1156] S.C. Nagel et al., "Developmental Exposure to a Mixture of Unconventional Oil and Gas Chemicals: A Review of Experimental Effects on Adult Health, Behavior, and Disease," *Molecular and Cellular Endocrinology* 513 (August 2020): 110722, https://doi.org/10.1016/j.mce.2020.110722.

different doses of a 23-chemical mixture which reflected realistic concentrations ranging from those found in surface and ground water in fracking-dense regions, to concentrations found in fracking wastewater. In human tissue culture cells, exposures to the chemical mixture showed "potent antagonist activity" for the estrogen, androgen, glucocorticoid, progesterone, and thyroid hormone receptors. In animal models, developmental exposures "profoundly impacted" pituitary hormones, reduced sperm counts, and altered maturation of the ovarian follicle. These exposures also altered the mammary gland ductal density and produced precancerous lesions. Finally, exposure additionally had effects on energy expenditure, behavior, and the immune system. The team concluded, "Taken together, these data suggest a strong need to examine the impacts of residential and occupational UOG exposure in humans and other wildlife in drilling areas."

- March 2, 2020 – University of Illinois environmental economists documented a causal link between fracking-related trucking and fatal traffic crashes in the Bakken Formation in North Dakota from 2006-2014.[1157] The researchers found that each additional post-fracking well within six miles of a road segments led to eight percent more fatal crashes and over seven percent higher per-capita costs in accidents. In their study, post-fracking wells were those horizontal wells completed in the previous month from which post-fracking wastewater flowback is a hauled to disposal sites. They extrapolated from their data "that an additional 17 fatal crashes occurred every year due to the fracking operations near the sampled 225 road segments… representing a 49% increase relative to the 2006 baseline crash counts of the eighteen drilling counties in North Dakota." They noted that an increase in alcohol-involved crash drivers was most likely "due to their vulnerability to heavier fracking- induced traffic rather than more alcohol-involved truck drivers near the fracking sites."

- January 27, 2020 – Pressured by families affected with rare childhood cancers in southwestern Pennsylvania, Governor Tom Wolf announced that his administration will spend $3 million to fund two studies to investigate the possible link between fracking and childhood cancers. Although an initial analysis had determined no "cancer cluster" existed in Washington County, it had had considered only three cases of the six cases known within a single school district. Nine preschoolers and students in the Canon-McMillan school district were diagnosed with rare cancers in the 2018-2019 school year. The state's chief epidemiologist, Sharon Watkins, said the results of the earlier analysis could change after more recent data is included. The first study will review existing literature on general health harms of fracking. The second will investigate whether young cancer patients had higher exposures to fracking than the general population.[1158] From 2006-2017, 31 people in four counties in southwestern Pennsylvania had been diagnosed with Ewing's sarcoma, a rare bone cancer. This represents a 40 percent jump from 1995-

[1157] Minhong Xu and Yilan Xu, "Fraccidents: The Impact of Fracking on Road Traffic Deaths," *Journal of Environmental Economics and Management* 101 (May 2020): 102303, https://doi.org/10.1016/j.jeem.2020.102303.
[1158] Chaffin, "Pennsylvania Governor Funds Research Examining Potential Fracking Health Impacts."

2005, a period prior to the arrival of drilling and fracking activities in the area.[1159] (See entry for May 14, 2019 below.)

- January 23, 2020 – Oil and gas development does not improve the "rural mortality penalty" according to an analysis of a large sample U.S. mortality rates from 2000-2016 and county-level counts of active wells.[1160] The rural mortality penalty is the phenomenon in which those living in rural locations have higher mortality rates than those in suburban and urban places. This began to be the case approximately a half century ago, increasing over time, with a further 75 percent increase between 2004 and 2016. Though fracking may increase job growth and earnings in some places, the author concluded, "Importantly, [unconventional oil and gas development] does not seem to improve mortality rates, suggesting that UOGE cannot address this unique problem. This raises several questions of justice and fairness, as host communities do not seem to retain all the potential benefits of UOGE."

- January 9, 2020 – Rates of two sexually transmitted infections, gonorrhea and chlamydia, were respectively fifteen and ten percent higher in Texas counties with high levels of fracking compared to those without, in a Yale School of Public Health study.[1161] The researchers considered the reported cases of these diseases, plus syphilis, from 2000-2016 in Texas, Colorado, and North Dakota. They sought to add to previous research on the link between increases in migrating and/or non-local workers and increased rates of sexually transmitted infections in host communities. Previous research took place in the Marcellus Shale formation states. Authors wrote, "Associations between shale drilling and chlamydia and gonorrhea in Texas are consistent with the previously observed associations in the Marcellus Shale, and may reflect increased risk in areas with greater drilling activity and increased proximity to major metropolitan areas." They expressed concern in the rise of both of these diseases; with gonorrhea due to the rise antibiotic-resistant infections, and chlamydia because asymptomatic people may not be treated.

- October 17, 2019 – Exposure to chemicals used in oil and gas development, such as benzene, may cause short-term negative health impacts including headaches, dizziness, respiratory effects, and skin and eye irritation at distances from 300 to 2000 feet from a well pad, concluded Colorado's state-funded human health risk assessment.[1162, 1163]The

[1159] Kris Maher, "After String of Rare Cancer Cases, Pennsylvania Investigates Potential Link to Fracking," *The Wall Street Journal*, December 20, 2019, sec. US, https://www.wsj.com/articles/after-string-of-rare-cancer-cases-pennsylvania-investigates-potential-link-to-fracking-11576837802.
[1160] Adam P. Mayer, "Can Unconventional Oil and Gas Reduce the Rural Mortality Penalty? A Study of U.S. Counties," *Journal of Rural and Community Development* 14, no. 4 (2019), https://journals.brandonu.ca/jrcd/article/view/1712.
[1161] Nicholaus P. Johnson et al., "A Multiregion Analysis of Shale Drilling Activity and Rates of Sexually Transmitted Infections in the United States," *Sexually Transmitted Diseases* 47, no. 4 (April 2020): 254–60, https://doi.org/10.1097/OLQ.0000000000001127.
[1162] Ed Carr et al., "Final Report: Human Health Risk Assessment for Oil & Gas Operations in Colorado" (ICF International for the Colorado Department of Public Health & Environment, 2019), https://www.fcgov.com/oilandgas/files/20191017-cdphe-healthimpactsstudy.pdf.
[1163] Jessica Bralish, "State Health Department Publishes Oil and Gas Health Risk Study | Department of Public Health & Environment," Press Release (Colorado Department of Public Health & Environment, October 17, 2019), https://cdphe.colorado.gov/press-release/state-health-department-publishes-oil-and-gas-health-risk-study.

study used actual emissions data from oil and gas operations in the state, to model exposures and risks of health impacts. The study did not use actual health impacts. This contracted assessment followed the state's 2017 small health impacts study, which called for further research into the possible health effects and exposures for people living close to wells. A peer-reviewed summary of this 2019 assessment was published in the *Journal of the Air & Waste Management Association*.[1164] *The Denver Post* reported, "While benzene has been linked to cancer, state officials said the study, based on measuring of emissions and computer modeling, did not find a basis for predicting long-term health harm."[1165] The regulating agency, Colorado Oil and Gas Conservation Commission, said that though they were not previously involved in testing air around residents' homes, they will "immediately begin reviewing more strictly all industry applications to drill new wells within 2,000 feet of homes and start measuring air emissions around industry sites." The study only addressed the scenario of a single well pad, not the risks for those living near large, multi-well pads.

- October 11, 2019 – The first analysis of infant health at birth and proximity to fracking in Oklahoma counties found a clear, detrimental relationship, by several measures.[1166] The analysis used 590,780 birth records across all 76 Oklahoma counties, from 2006–2017. Oklahoma's fracking boom began in 2006. Researchers determined distance between maternal residence and fracking wells, and their measures of infant health were total weight, low weight, and a composite health index of overall infant health. Researchers determined that 121,862 births took place within one kilometer of fracking wells, 148,783 births within five kilometers, 157,664 within ten, and 128,485 within 20 kilometers. The harmful effects of fracking wells on infant health were found for total birth weight and for the composite health index. For total birth weight, the results were significant within five kilometers and strongest within one kilometer. For the composite health index, the findings were significant across all distances, with the strongest impact taking place for maternal residence within one kilometer of fracking wells. These researchers also ran comparison analyses for conventional drilling, which constituted about 29 percent of Oklahoma drilling in the study period. They found more minor impacts, and at distances up to one kilometer only, concluding, "These findings provide supportive evidence to the substantial (negative) role of fracking drilling activities for infants' health status."

- August 15, 2019 – Building on their previous work that considered health-related symptoms of those living near fracking wells, researchers developed a study that added processing plants and compressor stations, while also creating the first such study to incorporate weather and atmospheric conditions in their exposure estimates. They

[1164] Chris Holder et al., "Evaluating Potential Human Health Risks from Modeled Inhalation Exposures to Volatile Organic Compounds Emitted from Oil and Gas Operations," *Journal of the Air & Waste Management Association* 69, no. 12 (December 2, 2019): 1503–24, https://doi.org/10.1080/10962247.2019.1680459.
[1165] Bruce Finley, "Colorado to Tighten Oversight of Oil and Gas Sites near Homes in Wake of Study Finding Possible Short-Term Health Effects," *The Denver Post*, October 17, 2019, https://www.denverpost.com/2019/10/17/colorado-oil-gas-health-risks-study/.
[1166] Nicholas Apergis, Tasawar Hayat, and Tareq Saeed, "Fracking and Infant Mortality: Fresh Evidence from Oklahoma," *Environmental Science and Pollution Research* 26, no. 31 (November 2019): 32360–67, https://doi.org/10.1007/s11356-019-06478-z.

analyzed respiratory health outcomes in a sample of 87 people living near fracking sites who participated in a Southwest Pennsylvania Environmental Health Project data collection project between February 1, 2012 and December 31, 2017. Seventy-two percent of the people studied reported at least one respiratory symptom "that began or worsened after the onset of drilling activity and could not be plausibly attributed to pre-existing or current medical conditions, or practices such as smoking."[1167] Forty percent reported sore throat, 36 percent reported both cough and shortness of breath, 26 percent reported sinus problems, and 16 percent report wheezing. Seventy-seven percent of those studied lived within two kilometers of at least one source, 29 percent within one to nine sources, one quarter within 10 to 19 sources, and 23 percent of those studied lived within two kilometers of 20 or more fracking-related exposure sources. Results showed some of the sources studied linked specifically to cough, shortness of breath, and "any respiratory symptom."

- July 25, 2019 – In this set of experimental studies in human tissue culture cells and laboratory animals, exposure to a mixture of fracking chemicals was linked to potent hormone disrupting activity.[1168] This paper presented results that were part of a set of coordinated studies carried out collaboratively by an interdisciplinary team using four different doses of a 23-chemical mixture, reflecting realistic concentrations ranging from those found in surface and ground water in fracking-dense regions, to concentrations found in fracking wastewater (see March 4, 2020 entry above and May 22, 2019 below). In the human tissue culture cells, exposure to the mixture was linked to "potent antagonist activity for the estrogen, androgen, glucocorticoid, progesterone, and thyroid receptors." In a laboratory mouse model, the fracking chemical mixture given in pregnancy led to profound impacts on health and behavior in the developing and adult offspring. Offspring had reduced sperm counts, altered ovarian follicle development, and precancerous lesions. The mixture impacted energy expenditure, exploratory and risk-taking behavior, and the immune system. The research also found immune system effects in a frog model. Using these different model systems and demonstrating various physiological impacts, the researchers concluded that fracking "may be an important source of human [endocrine disrupting chemical] exposure and altered health parameters."

- July 23, 2019 – Researchers found 4.3 additional cases of prenatal anxiety or depression per 100 women, among mothers who lived amid the most fracking activity during their pregnancies, compared to those who lived around less.[1169] The study included 7,715 mothers without anxiety or depression at the time of conception, who delivered their

[1167] David R. Brown et al., "Assessing Exposure to Unconventional Natural Gas Development: Using an Air Pollution Dispersal Screening Model to Predict New-Onset Respiratory Symptoms," *Journal of Environmental Science and Health, Part A* 54, no. 14 (December 6, 2019): 1357–63, https://doi.org/10.1080/10934529.2019.1657763.
[1168] Victoria D. Balise et al., "Developmental Exposure to a Mixture of Unconventional Oil and Gas Chemicals Increased Risk-Taking Behavior, Activity and Energy Expenditure in Aged Female Mice After a Metabolic Challenge," *Frontiers in Endocrinology* 10 (July 25, 2019): 460, https://doi.org/10.3389/fendo.2019.00460.
[1169] Joan A. Casey et al., "Unconventional Natural Gas Development and Adverse Birth Outcomes in Pennsylvania: The Potential Mediating Role of Antenatal Anxiety and Depression," *Environmental Research* 177 (October 2019): 108598, https://doi.org/10.1016/j.envres.2019.108598.

babies at Geisinger Health System in central and northeast Pennsylvania, between January 2009 and January 2013. It included women who gave birth to single babies, without serious birth defects, and of viable weight and gestational age. In the highest quartile of the fracking activity metric developed for this study there were an average of 130 wells within 20 kilometers of the mothers' home, compared to 10 wells for mothers in the other three quartiles. The prevalence of anxiety or depression during pregnancy was 15 percent in the highest quartile, and 11 percent in the lower three quartiles. Researchers determined that the risk was greatest among low income women, among whom there were 5.6 additional cases of anxiety or depression per 100. In this study, researchers did not find a relationship between anxiety or depression during pregnancy and preterm birth and reduced term birth weight, though the same team found a link between proximity to fracking and these adverse birth outcomes.

- July 18, 2019 – Colorado mothers living in areas with the most intense levels of oil and gas activity were 40 to 70 percent more likely to have children with congenital heart defects (CHDs) in a study 3,324 of infants born in the state from 2005-2011.[1170] University of Colorado researchers developed a measure of the monthly intensity oil and gas well activity around mothers' residences from three months prior to conception through the second month of pregnancy, including the phase of oil and gas development, the size of well sites, and production volumes. These considerations as well as other features of this study, such as additional checks on the infants' diagnoses, built on previous research documenting the link between proximity to oil and gas and CHDs. Some of the most common hazardous air pollutants emitted from drilling and fracking sites are "suspected teratogens that are known to cross the placenta." CHDs are a leading cause of developmental problems, brain injury, and death among infants with birth defects. The four specific defects addressed were aortic artery and valve (AAVD), pulmonary artery and valve (PAVD), conotruncal (CTD), and tricuspid valve (TVD) defects. Authors concluded that the study provided further evidence of a link between maternal proximity to drilling and fracking and several types of CHDs, particularly in rural areas, where chances of an infant born with AAVD, CTD, or TVD were 2.6 to 4.6 times more likely in the high exposure group compared to the low exposure group. With regard to urban areas, authors wrote that it is likely that other sources of air pollution obscured possible links.

- July 12, 2019 – The driver of a tractor-trailer rig and four oil field workers riding in a pickup truck were killed in a head-on crash along New Mexico State Route 128, one of several highways experiencing increased crashes in "the busiest oil and gas region in the United States.[1171] Crashes along this route, as well as New Mexico State Route 31 and U.S. 285, have increased over the last year, as upkeep, patrols, and interventions such as

[1170] Lisa M. McKenzie, William Allshouse, and Stephen Daniels, "Congenital Heart Defects and Intensity of Oil and Gas Well Site Activities in Early Pregnancy," *Environment International* 132 (November 2019): 104949, https://doi.org/10.1016/j.envint.2019.104949.
[1171] Susan Montoya Bryan, "Police: Texas Oilfield Workers, Truck Driver Killed in Fiery Crash," *Midland Reporter-Telegram*, July 12, 2019, sec. News, https://www.mrt.com/news/article/State-Police-5-dead-in-collision-in-southeastern-14091816.php.

safety corridors do not keep pace with the significant increase in traffic and driver behavior issues brought by the fracking boom.

- June 26, 2019 – The investigative journalism organization *Searchlight New Mexico* examined trends in fracking-region highway deaths, their circumstances, and community reactions, reporting, "Locals have a new name for the section of US 285 where [local men] Ponce and Martinez perished: Death Highway."[1172] In 2018, there were 49 crashes, up from 31 crashes in 2017. There were five deaths resulting from the crashes along this highway in 2017 and two in 2018. "For local residents—especially those living in rural areas—the combination of congestion, roads thick with truck traffic, unsafe driver behavior, poorly maintained vehicles and deteriorating pavement can make even a routine trip to the farm supply store a white-knuckle obstacle course." According to research by an Albuquerque engineering and planning firm, most of the crashes were caused by speeding. Another group said that a scarcity of local qualified drivers, and many drivers hired by oil companies unfamiliar with the region, are key to the problem. Finally, government funding for needed road improvements is inadequate, according to the *Searchlight* report.

- May 22, 2019 – Exposure of laboratory mice to an environmentally relevant mixture of 23 fracking chemicals altered developmental programming, resulting in changed energy expenditure and activity in adult female offspring.[1173] Part of an ongoing set of studies examining the endocrine disruption effects of this mixture using laboratory animals and human tissue culture cells (see also March 4, 2020 and July 25, 2019, above), this was the first study to examine these direct developmental effects of exposure to fracking chemicals. Researchers exposed female mice the mixture of five weeks prior to mating, and from the first day of gestation day to the 21st day postnatally. Pre- and post-natal exposure to the fracking chemical mixture decreased total and resting energy expenditure in some of the groups, but it was not linked with altered body weight or body composition in the adult females. Researchers wrote that although "one would typically expect higher body mass or fat mass to track with lower energy expenditure, this is not always the case."

- May 14, 2019 – A pilot study in northeastern British Columbia reported elevated levels of barium and strontium in urine and hair samples of pregnant indigenous women living in an area of intense fracking activity. These trace metals, released during hydraulic fracturing, are known developmental toxicants. The researchers cited the need for systematic water monitoring program in the region, and, following this small pilot study, they intend to "carry out a multi-faceted study to assess exposure to contaminants including trace metals with more precision."[1174]

[1172] April Reese, "Death Highway," *Searchlight New Mexico*, June 27, 2019, https://searchlightnm.org/death-highway/.
[1173] Victoria D. Balise et al., "Preconceptional, Gestational, and Lactational Exposure to an Unconventional Oil and Gas Chemical Mixture Alters Energy Expenditure in Adult Female Mice," *Frontiers in Endocrinology* 10 (May 22, 2019): 323, https://doi.org/10.3389/fendo.2019.00323.
[1174] Élyse Caron-Beaudoin et al., "Urinary and Hair Concentrations of Trace Metals in Pregnant Women from Northeastern British Columbia, Canada: A Pilot Study," *Journal of Exposure Science & Environmental Epidemiology* 29, no. 5 (September 2019): 613–23, https://doi.org/10.1038/s41370-019-0144-3.

- May 14, 2019 – An investigation by the *Pittsburgh Post-Gazette* documented 27 cases of Ewing's sarcoma, a rare bone cancer that tends to strike children and young adults, in four counties in southwestern Pennsylvania (Fayette, Greene, Washington, and Westmoreland) that are at the heart of the Marcellus fracking boom and where more than 3,500 wells have been drilled since 2008.[1175] Six cases occurred in the same school district. (The typical rate is 250 cases of Ewing's sarcoma per year in the United States as a whole.) This cancer has no known cause but does not appear to have hereditary links. There are also high numbers of other rare cancers in the region, which is home to several polluting legacy industries. The *Post-Gazette* documented ten such rare cancers Washington County's Canon-McMillan School District alone and tallied 13 childhood and young adult cancer deaths in the region since 2011, including three since 2015 in the West Greene School District. In April 2019, the Pennsylvania Department of Health reported "no conclusive findings" of a cancer cluster in the Canon-McMillan School District and Washington County.[1176] Subsequently, additional cases came to light, and public calls for more comprehensive investigations continued.[1177, 1178, 1179, 1180]

- April 15, 2019 – Overall, oil and gas booms had very modest effects on local alcohol consumption in a U.S.-wide study using county-level data, but the effects varied greatly across states and by gender.[1181] Taken as a whole, oil and gas production slightly increased heavy drinking for males and slightly decreased binge drinking for females. Researchers recommended that data be gathered at smaller spatial scales rather than by county, and that hospital admissions or arrest records could provide further insight into this question.

[1175] David Templeton and Don Hopey, "Are the 27 Cases of Ewing's Sarcoma near Pittsburgh a Cluster?," *Pittsburgh Post-Gazette*, May 14, 2019, https://newsinteractive.post-gazette.com/blog/ewing-sarcoma-cancer-cluster-pittsburgh-washington-westmoreland/.
[1176] Pennsylvania Department of Health, "Ewing's Family of Tumors, Childhood Cancer, and Radiation-Related Cancer Incidence Review for Washing County and Canon-McMillan School District in Pennsylvania" (Bureau of Epidemiology, Division of Community Epidemiology, April 22, 2019), https://www.documentcloud.org/documents/5975464-Ewings-Washington-Fmt.html.
[1177] Reid Frazier, "'Something's Wrong Here': Washington County Parents Want Pa. to Look Deeper at Whether Fracking Could Be Related to Cancer Cases," *State Impact Pennsylvania*, June 28, 2019, https://stateimpact.npr.org/pennsylvania/2019/06/28/somethings-wrong-here-washington-county-parents-want-pa-to-look-deeper-at-whether-fracking-could-be-related-to-cancer-cases/.
[1178] Deb Erdley, "Southwestern Pennsylvania Residents Renew Calls for Research on Possible Health Impact of Fracking," October 12, 2019, https://triblive.com/local/regional/southwestern-pennsylvania-residents-renew-calls-for-research-on-possible-health-impact-of-fracking/.
[1179] David Templeton and Don Hopey, "The Human Toll-Risk and Exposure in the Gas Lands," *Pittsburgh Post-Gazette*, May 14, 2019, https://newsinteractive.post-gazette.com/childhood-cancer-pittsburgh-pennsylvania-canon-mcmillan-pollution/.
[1180] Editorial Board, "Young Lives at Stake: Rural Areas Deserve Answers on Child Cancers," *Pittsburgh Post-Gazette*, May 22, 2019, https://www.post-gazette.com/opinion/editorials/2019/05/22/childhood-cancer-pittsburgh-pennsylvania-canon-mcmillan-pollution-rural-areas-greene-fayette-washington-westmoreland/stories/201905220064.
[1181] Adam Mayer and Shawn Olson Hazboun, "Does Fracking Drive You to Drink? Unconventional Oil and Gas Production and Alcohol Consumption in U.S. Counties," *The Extractive Industries and Society* 6, no. 3 (2019): 823–30, https://doi.org/10.1016/j.exis.2019.04.002.

- January 21, 2019 – Increased hospitalizations for diseases of the genitourinary system, such as urinary tract infections, kidney infections, and kidney stones, were "strongly and positively associated with cumulative [unconventional natural gas] well density" in Pennsylvania.[1182] The strongest association for the genitourinary hospitalization rates was for women aged 20 to 64, particularly for kidney infections, stones in the ureter, and urinary tract infections. The researchers compared yearly hospitalization rates for each of Pennsylvania's 67 counties with the number of new fracking wells drilled, the total number of wells, and the density of wells by land area for each county by year, from 2003-2014. Noting that hospitalizations, in contrast with outpatient physician visits, reflect acute illness or serious exacerbations of chronic disease, the research team pointed out that these same health problems addressed in an outpatient setting, or not addressed at all, were likely also rising but would not have been counted in this study. The findings also revealed a link between cumulative gas well exposure measures and hospitalization rates for skin problems, particularly among men aged 20 to 64.

- December 12, 2018 – University of Oklahoma public health scientists found a significantly increased prevalence of neural tube defects among children whose birth residence was located within two miles of a drilling and fracking site, compared to those which were not.[1183] The researchers examined records of all 476,600 singleton births and congenital anomalies in Oklahoma from 1997 through 2009, together with historical location and production data on active natural gas wells for each year of the study. No stillbirths were included in this study. Hence, as the researchers note, the link they found would likely be an underestimate "if natural gas activity is related to severe anomalies with high prenatal mortality."

- December 6, 2018 – Early signs of cardiovascular disease—including high blood pressure, changes in the stiffness of blood vessels, and markers of inflammation—occurred more often in people who live in communities with more intense oil and gas development, according to a study of 97 adults living in northeastern Colorado between October 2015 and May 2016.[1184] Artery stiffness, as measured by augmentation index, was highest among people living in areas with the greatest drilling and fracking activity, as was systolic and diastolic blood pressure (for those not taking prescription medications). This was the first study to evaluate, with direct measurements, indicators of cardiovascular disease and the intensity of oil and gas activity. The results are consistent with previous research showing increased rates of cardiology inpatient hospital admission in these areas.

[1182] A. Denham et al., "Unconventional Natural Gas Development and Hospitalizations: Evidence from Pennsylvania, United States, 2003–2014," *Public Health* 168 (2019): 17–25, https://doi.org/10.1016/j.puhe.2018.11.020.
[1183] Amanda E. Janitz et al., "The Association between Natural Gas Well Activity and Specific Congenital Anomalies in Oklahoma, 1997–2009," *Environment International* 122 (2019): 381–88, https://doi.org/10.1016/j.envint.2018.12.011.
[1184] Lisa M. McKenzie et al., "Relationships between Indicators of Cardiovascular Disease and Intensity of Oil and Natural Gas Activity in Northeastern Colorado," *Environmental Research* 170 (2019): 56–64, https://doi.org/10.1016/j.envres.2018.12.004.

- August 28, 2018 – The top 10 oil and gas producing counties in Colorado had higher truck accident rates than the remaining 54 counties in an analysis by Colorado School of Public Health researchers. Researchers also performed an additional geospatial study technique called a "grid level analysis" using the Colorado Oil and Gas information System (COGIS), census population information, and home locations. These results showed that grid cells with more homes and/or wells were associated with more truck accidents, as well as with more multi-vehicle truck accidents with an injury.[1185]

- August 13, 2018 – Babies in Pennsylvania whose mothers lived near at least one gas well during their pregnancies were at higher risk for adverse birth outcomes, according to a study published in the *Journal of Health Economics.* This investigation examined state-based data on the locations of 2,459 natural gas wells drilled between 2006 and 2010 together with restricted-access birth and mortality data for the years 2003–2010.[1186] Mothers living within 2.5 kilometers (1.5 miles) of gas wells gave birth to infants with increased incidence of low birth weight and small for gestational age (SGA). SGA generally increases with exposure to environmental pollution and helps determine immediate health care needs, as well as predicting long-term adverse health outcomes. In addition, the study found term birth weight for these infants was lower on average, and the prevalence of APGAR scores less than eight was increased by 26 percent. APGAR scores are used to evaluate the health of infants immediately after birth. This study builds on growing evidence that air pollution from shale gas development damages infant health and stands out for thoroughly controlling for predictors of infant health and for estimating the extensive and intensive margins of drillings. Within the intensive margin (which includes an estimation of the impact of well density), one additional well was associated with a seven percent increase in low birth weight, a five gram reduction in term birth weight, and a three percent increase in premature birth. Each of these adverse outcomes carries high associated medical costs. The author conservatively estimated the added cost associated with one low birth weight infant to be $96,500 in the first year alone, not counting any loss of parent income. The author noted that these impacts are "likely to persist throughout these children's lives."

- August 10, 2018 – A study of Pennsylvania counties focusing on the period 2003–2012 found that counties with fracking activities have higher rates of gonorrhea and chlamydia infections (up 7.8 percent and 2.6 percent, respectively), as well as a 19.7 percent higher rate of prostitution-related arrests.[1187] Authors found no evidence that confounding factors such as opioid prescription rates, viral hepatitis deaths, or drug abuse arrests influenced these results. These findings provide "strong evidence that unconventional or shale gas development poses significant risks to public health and that unconventional or

[1185] Benjamin Blair et al., "Truck and Multivehicle Truck Accidents with Injuries Near Colorado Oil and Gas Operations," *International Journal of Environmental Research and Public Health* 15, no. 9 (2018): 1861, https://doi.org/10.3390/ijerph15091861.
[1186] Elaine L. Hill, "Shale Gas Development and Infant Health: Evidence from Pennsylvania," *Journal of Health Economics* 61 (2018): 134–50, https://doi.org/10.1016/j.jhealeco.2018.07.004.
[1187] Trinidad Beleche and Inna Cintina, "Fracking and Risky Behaviors: Evidence from Pennsylvania," *Economics & Human Biology* 31 (2018): 69–82, https://doi.org/10.1016/j.ehb.2018.08.001.

shale gas development has policy implications beyond the economic and environmental impacts often cited."

- July 28, 2018 – Road fatalities in the Permian Basin region of west Texas have risen and fallen with the price of oil, according to an investigative piece in *Bloomberg* using New York Mercantile Exchange and Texas Department of Transportation data.[1188] Interviewees in the article pointed to inexperienced and exhausted drivers, sinkholes, oversized trucks on roads not designed for the amount of traffic they now carry, and other factors as reasons for the ongoing fatalities.

- July 27, 2018 – In this study of almost 5,000 Pennsylvanians, a team of medical and public health scientists found a link between living closer to more and bigger unconventional shale gas wells and increased symptoms of depression. This is the first epidemiologic study to address a mental health outcome with regard to proximity to fracking and related operations. The researchers combined information from a mailed questionnaire, electronic health record data, and residential proximity to more and bigger wells, using well data from three agencies. Size of wells was ascertained by combining data on total well depth and volume of natural gas produced. Researchers concluded that drilling and fracking activities "may be associated with adverse mental health in Pennsylvania" and called for including potential mental health consequences in future risk-benefit calculations.[1189]

- June 21, 2018 – Using individual inpatient data for the whole state of Pennsylvania from 2003 through 2014, researchers found consistent associations between childhood asthma hospitalizations and nearby drilling and fracking activity. When they compared unexposed children to children in the top third of patients exposed to shale gas drilling, the research team found that, during the same calendar quarter a gas well was drilled, the odds of children and adolescents being hospitalized for asthma increased by 25 percent. If there was ever a well drilled within a zip code, the odds of these pediatric asthma-related hospitalizations increased by 19 percent. This finding demonstrates that the increased risk remains for years after wells are drilled.[1190] This study is notable because it is the first to control for 180 pre-existing respiratory health risks. Researchers also considered specific air emissions from drilling and fracking sites. They found that increased levels of 2,2,4-trimethylpentane, carbon dioxide, formaldehyde, nitrous oxide, volatile organic compounds (VOCs), and x-hexane were associated with increased risks of pediatric asthma hospitalizations across age groups, as well as links for younger children to additional pollutants.

[1188] Ryan Collins and Rachel Adams-Heard, "`Death Highway' Is Where Oil Prices, Truck Fatalities Intersect," *Bloomberg.Com*, July 28, 2018, https://www.bloomberg.com/news/articles/2018-07-28/-death-highway-is-where-oil-prices-truck-fatalities-intersect.

[1189] Joan A. Casey et al., "Associations of Unconventional Natural Gas Development with Depression Symptoms and Disordered Sleep in Pennsylvania," *Scientific Reports* 8, no. 1 (2018): 11375, https://doi.org/10.1038/s41598-018-29747-2.

[1190] Mary D. Willis et al., "Unconventional Natural Gas Development and Pediatric Asthma Hospitalizations in Pennsylvania," *Environmental Research* 166 (2018): 402–8, https://doi.org/10.1016/j.envres.2018.06.022.

- May 21, 2018 – Using the most stringent classification within and across countries internationally, researchers examined reproductive toxicity among chemicals used in drilling and fracking operations for oil and gas. They found that 43 chemicals are classified as known or presumed human reproductive toxicants, while 31 others are suspected human reproductive toxicants. The team, which included Yale School of Medicine and School Public of Health researchers, further analyzed the 43 reproductive toxicants for their carcinogenic and mutagenic properties and found that seven reproductive toxicants doubled as carcinogens and mutagens. They are potassium dichromate, cadmium, benzene, ethylene oxide, nickel sulfate, N,N-dimethylformamide, and lead. Of these, benzene and lead are found in both fracking fluid and in fracking wastewater. Researchers noted that their study was limited to 157 chemicals previously identified as having evidence of reproductive toxicity, which is only a fraction of the more than 1000 chemicals identified as being present in fracking fluid, fracking wastewater, and fracking-related air emissions. They recommended that their framework be extended to all those chemicals.[1191] (See also entry for January 6, 2016 in Water Contamination.)

- May 1, 2018 – In a laboratory study, prenatal exposure to fracking-related chemicals triggered immune problems in mice, especially females. All three immune system illnesses tested—a house dust mite-induced allergic disease, influenza A virus, and a disease similar to multiple sclerosis—were impaired in mice exposed in the womb to a mixture of fracking chemicals.[1192] Using a chemical mixture "laced with chemicals at levels similar to those found in groundwater near fracking sites" and already demonstrated to have harmful developmental and reproductive effects, the researchers found sex-linked effects.[1193] The exposed female mice showed more severe damage to their immune systems and ability to resist disease. In addition, the multiple scleroris-like disease, experimental autoimmune encephalomyelitis, developed earlier and more severely in female mice as compared to male mice. Authors concluded, "These observations suggest that developmental exposure to complex mixtures of water contaminants, such as those derived from [drilling and fracking] operations, could contribute to immune dysregulation and disease later in life."

- March 23, 2018 – Yale University public health scientists investigated possible connections between shale gas drilling and sexually transmitted diseases in Ohio. They found that, compared to counties with no shale gas activity, counties with high activity had 21 percent increased rates of chlamydia and 19 percent increased rates of

[1191] Salmaan H. Inayat-Hussain et al., "Prioritization of Reproductive Toxicants in Unconventional Oil and Gas Operations Using a Multi-Country Regulatory Data-Driven Hazard Assessment," *Environment International* 117 (2018): 348–58, https://doi.org/10.1016/j.envint.2018.05.010.
[1192] L. A. Boulé et al., "Developmental Exposure to a Mixture of 23 Chemicals Associated With Unconventional Oil and Gas Operations Alters the Immune System of Mice," *Toxicological Sciences* 163, no. 2 (2018): 639–54, https://doi.org/10.1093/toxsci/kfy066.
[1193] Beth Adams, "Exposure to Chemicals Used in Fracking Impairs Immune System of Mice in URMC Study," *WXXI News*, May 1, 2018, https://www.wxxinews.org/post/exposure-chemicals-used-fracking-impairs-immune-system-mice-urmc-study.

gonorrhea.[1194] They classified all 88 counties in the state as having none, low, and high shale gas activity in each year from 2000 through 2016, using Ohio Department of Natural Resources data. Their findings showed magnitude of effect for the association with gonorrhea that is similar to a prior analysis, adding strength to observed associations. Speaking to the *Columbus Dispatch*, the lead author noted, "Although there has been a decrease in new permits in recent years, [sexually transmitted infection] rates continue to climb because once a disease is introduced… it can be exchanged within the communities even after the workers leave."[1195]

- March 20, 2018 – In the Texas Barnett Shale, women with homes within a half-mile radius of the most dense gas drilling activity or gas production activity at the time of their child's birth had, respectively, 20 percent and 15 percent higher risk of preterm birth, compared with women with no such activity near their residence. The greatest proximity-related risk was for extremely premature births (prior 28 weeks' gestation): mothers living near the densest drilling activity and the densest production activity were, respectively, 100 percent and 53 percent more likely to give birth to extremely premature babies.[1196, 1197] For purposes of this study, the drilling phase included drilling of the wellbore, installation of casing, and fracking, whereas the production phase, which can last for years, included the flowback of gas, condensate, and produced water, as well as possible on-site storage of these materials. Researchers noted that they did not have access to information that would have allowed more refined classification of phases. The study included 13,332 preterm birth cases and 66,933 term births in the 24-county Barnett Shale region between 2010 and 2012. The study also addressed trimester-specific differences in risk, finding little evidence for that factor. (See also entry for September 19, 2017.)

- March 13, 2018 – A research team found higher rates of hospitalizations for pneumonia among individuals ages 65 and older in Pennsylvania counties with drilling and fracking operations compared to those without. This result is consistent with other studies reporting links between respiratory problems and air pollution. This study, which used enhanced county-specific data from 2001 to 2013, expands on earlier research in its geographical reach and longer time horizon. The research team also found higher average hospitalization rates for other air pollution-sensitive diseases (acute myocardial infarction, chronic obstructive pulmonary disease, asthma, and upper respiratory infections) in counties containing unconventional natural gas wells than in those without

[1194] Nicole C. Deziel et al., "Shale Gas Activity and Increased Rates of Sexually Transmitted Infections in Ohio, 2000–2016," ed. Jaymie Meliker, *PLoS ONE* 13, no. 3 (2018): e0194203, https://doi.org/10.1371/journal.pone.0194203.
[1195] Abbey Marshall, "Study Suggests Potential Link between Fracking Industry and Increased Sexually Transmitted Infections," *The Columbus Dispatch*, July 22, 2018, https://www.dispatch.com/news/20180722/study-suggests-potential-link-between-fracking-industry-and-increased-sexually-transmitted-infections.
[1196] Kristina Walker Whitworth, Amanda Kaye Marshall, and Elaine Symanski, "Drilling and Production Activity Related to Unconventional Gas Development and Severity of Preterm Birth," *Environmental Health Perspectives* 126, no. 3 (2018): 037006, https://doi.org/10.1289/EHP2622.
[1197] Lindsey Konkel, "Drilling into Critical Windows of Exposure: Trimester-Specific Associations between Gas Development and Preterm Birth," *Environmental Health Perspectives* 126, no. 10 (2018): 104002, https://doi.org/10.1289/EHP3762.

wells, but those links were not as strong statistically as for pneumonia among the elderly. Noting that their study design may actually underestimate the impact of natural gas development on pneumonia, the research team stated that their study "helps establish a consistent link between unconventional natural gas extraction and higher rates of disease."[1198]

- February 7, 2018 – Female mice exposed to a mixture of 23 fracking chemicals during early life developed dose-specific abnormalities in their mammary glands. The researchers saw changes in tissue morphology, cell proliferation, "and the induction of unique intraductal hyperplasias."[1199] (Intraductal hyperplasia is an overgrowth of cells that is considered a marker for future breast cancer risk.) Researchers used four doses; the lower two used were equivalent to concentrations found in drinking water in fracking regions and the highest dose represented concentrations that have been measured in industry wastewater. Mammary gland effects varied for each the doses, but all groups developed intraductal hyperplasia. According to a co-author, "This study shows that a mixture of [fracking] chemicals can affect the long-term health of the mouse mammary gland, even after low level exposures in the womb."[1200]

- January 15, 2018 – A study of urban oil drilling in two Los Angeles neighborhoods found elevated asthma rates among residents living within 1,500 feet of oil wells. Researchers compared diagnosed asthma rates in these areas to a representative comparison area (the California Health Interview Survey's "SPA6" in South Los Angeles) and to Los Angeles County as a whole.[1201] The diagnosed asthma rates in the two study areas were statistically significantly higher (16.1 percent and 23.6 percent) than the comparison area (9.8 percent). Asthma prevalence in one of the two study areas was significantly higher than that in Los Angeles County as a whole. Households with smokers were excluded from the analysis. This interdisciplinary team worked in partnership with the local residents to conduct this community-based survey with limited resources and urged further studies with more complex scientific design.

- December 13, 2017 – A team of health economists analyzed fracking's health impacts on infants. They examined birth certificates for all 1.1 million infants born in Pennsylvania between 2004 and 2013 and combined these data with maps showing when and where gas wells were drilled in the state. Their results indicated that the introduction of fracking "reduces health among infants born to mothers living within 3 km (1.9 miles) of a well site during pregnancy." For mothers living within one kilometer (.6 miles), they found a

[1198] Lizhong Peng, Chad Meyerhoefer, and Shin-Yi Chou, "The Health Implications of Unconventional Natural Gas Development in Pennsylvania," *Health Economics* 27, no. 6 (2018): 956–83, https://doi.org/10.1002/hec.3649.
[1199] Sarah A Sapouckey et al., "Prenatal Exposure to Unconventional Oil and Gas Operation Chemical Mixtures Altered Mammary Gland Development in Adult Female Mice," *Endocrinology* 159, no. 3 (2018): 1277–89, https://doi.org/10.1210/en.2017-00866.
[1200] University of Massachusettsat Amherst, "Changes in Mouse Breast Tissue after Exposure to Fracking Chemicals: UMass Amherst, University of Missouri Led First Study of Such Effects," *ScienceDaily*, February 7, 2018, https://www.sciencedaily.com/releases/2018/02/180207090108.htm.
[1201] Bhavna Shamasunder et al., "Community-Based Health and Exposure Study around Urban Oil Developments in South Los Angeles," *International Journal of Environmental Research and Public Health* 15, no. 1 (2018): 138, https://doi.org/10.3390/ijerph15010138.

25 percent increase in the probability of low birth weight, "significant declines" in average birth weight, as well as declines in other measures of infant health. They also observed reductions in infant health when mothers lived within one to three kilometers of a fracking site; these were about one-third to one-half of the declines of those mothers living closer.[1202] The researchers estimated that "about 29,000 out of the nearly 4 million U.S. births (0.7 percent) annually occur within 1 kilometer of a fracking site and 95,500 are born within 3 kilometers." "For policymakers weighing the costs and benefits of fracking before deciding whether to allow it in their communities, this study provides a clear cost: an increase in the probability of poorer health for babies born near these sites."[1203]

- November 6, 2017 – As part of a pilot project, a team of Montreal-based public health researchers evaluated exposure of pregnant mothers to VOCs in an area of intensive fracking in northeastern British Columbia. At least 28,000 unconventional natural gas wells had been drilled to date in the Peace River Valley. Analyzing the urine of 29 pregnant women, researchers found high concentrations of muconic acid, which is a degradation product of benzene, a widely studied developmental toxicant and an air contaminant in the vicinity of gas wells. The median concentration of this chemical was approximately 3.5 times higher in the study group than in the general Canadian population. In five of the 29 women, the concentration of muconic acid exceeded an exposure index by the American Conference of Governmental Industrial Hygienists that was designed for workplace settings. (No guidelines for the public exist.) By design, this small pilot study sets the groundwork for more extensive biomonitoring and environmental analysis.[1204]

- September 19, 2017 – University of Texas Health Science Center researchers conducted a case-control study nested within their larger cohort of women with single births (see entry for July 21, 2017, below) in the 24-county Barnett Shale between November 30, 2010 and November 29, 2012. Its specific purpose was to consider timing of unconventional gas development activity "during potentially sensitive windows of exposure," as well as "potential differences in risk by UGD drilling phase," with regard to preterm births. Results suggest a link between maternal residential proximity to UGD-activity and preterm births, which were similar by drilling phase and "slightly stronger in the first two trimesters of pregnancy."[1205]

[1202] Janet Currie, Michael Greenstone, and Katherine Meckel, "Hydraulic Fracturing and Infant Health: New Evidence from Pennsylvania," *Science Advances* 3, no. 12 (2017): e1603021, https://doi.org/10.1126/sciadv.1603021.
[1203] Janet Currie, Michael Greenstone, and Katherine Meckel, "Hydraulic Fracturing and Infant Health: New Evidence from Pennsylvania," Research Summary (Energy Policy Institute at the University of Chicago, 2017), https://epic.uchicago.edu/wp-content/uploads/2019/07/Research-Summary-5.pdf.
[1204] Élyse Caron-Beaudoin et al., "Gestational Exposure to Volatile Organic Compounds (VOCs) in Northeastern British Columbia, Canada: A Pilot Study," *Environment International* 110 (2018), https://doi.org/10.1016/j.envint.2017.10.022.
[1205] Amanda Marshall, Elaine Symanski, and Kristina Whitworth, "The Association Between Unconventional Gas Development and Preterm Birth: Evaluating Drilling Phases and Critical Windows of Susceptibility," *Annals of Epidemiology* 27, no. 8 (2017): 530.

- September 14, 2017 – Researchers reviewed health assessments taken between February 2012 and October 2015 of adults in Pennsylvania communities with intense unconventional natural gas development (UNGD). The most frequently reported symptoms were sleep disturbance, headache, throat irritation, stress/anxiety, cough, shortness of breath, sinus problems, fatigue, wheezing, nausea, each occurring in over 20 percent of the sample. Over 43 percent of the sample reported sleep disturbance. To meet the inclusion criteria, as developed and implemented by a physician and nurse practitioner, the symptoms were reviewed to ensure no plausible cause relating to "past medical and surgical history, concurrent medical conditions, family and social history, and environmental exposures unrelated to UNGD. For example, if the social history indicated a ½ pack/day smoking history, the symptom of 'difficulty breathing' was not included." Independently, the timing of the exposure for each symptom that met the inclusion criteria was determined, using the beginning drilling date for each unconventional natural gas well within one kilometer (.6 miles) of the patient's residence; records were excluded if it was not possible to verify at least one gas well within this distance.[1206]

- August 21, 2017 – Using county-level data from 2003 to 2013, researchers found that, all together, counties in the Marcellus Shale region that experienced a boom in hydraulic fracturing showed a 20 percent increase in the incidence rate of gonorrhea.[1207]

- July 21, 2017 – A University of Texas Health Science Center School of Public Health team assessed the links between the residential proximity of pregnant mothers to unconventional natural gas development activity and various newborn health problems: preterm birth, small-for-gestational age (SGA), fetal death, and low birth weight. They found evidence of a "moderate positive association" between residential proximity to UGD-activity and increased odds of preterm birth, and a "suggestive association" with fetal death. Nearly 159,000 births and fetal deaths from November 30, 2010 to November 29, 2012 in the 24-county Barnett Shale area were considered.[1208]

- February 15, 2017 – A study from the University of Colorado School of Public Health and Anschutz Medical Campus showed that children and young adults between the ages of 5 and 24 with acute lymphocytic leukemia (ALL) were 4.3 times more likely to live in area dense with active oil and gas wells. The researchers did not find such a link with ALL cases in 0-4 year olds, or with incidence of non-Hodgkin lymphoma. The study focused on rural areas and towns in 57 Colorado counties and did not include cities of more than 50,000 people. Authors wrote, "Because oil and gas development has potential

[1206] Beth Weinberger et al., "Health Symptoms in Residents Living near Shale Gas Activity: A Retrospective Record Review from the Environmental Health Project," *Preventive Medicine Reports* 8 (2017): 112–15, https://doi.org/10.1016/j.pmedr.2017.09.002.
[1207] Tim Komarek and Attila Cseh, "Fracking and Public Health: Evidence from Gonorrhea Incidence in the Marcellus Shale Region," *Journal of Public Health Policy* 38, no. 4 (2017): 464–81, https://doi.org/10.1057/s41271-017-0089-5.
[1208] Kristina W. Whitworth, Amanda K. Marshall, and Elaine Symanski, "Maternal Residential Proximity to Unconventional Gas Development and Perinatal Outcomes among a Diverse Urban Population in Texas," ed. Jaymie Meliker, *PLoS ONE* 12, no. 7 (2017): e0180966, https://doi.org/10.1371/journal.pone.0180966.

to expose a large population to known hematologic carcinogens, such as benzene, further study is clearly needed to substantiate both our positive and negative findings."[1209]

- October 26, 2016 – A study that investigated possible links between fracking and cancer incidence in southwest Pennsylvania found elevated rates of bladder and thyroid cancers in six counties with shale gas activity.[1210] Bladder cancer was elevated in both males and females, with a 10 percent increase in the number of observed cases from 2000 to 2012. Over the same time period, thyroid cancer jumped even more dramatically. "There was a huge 91.2% increase in the number of observed cases from 2000 to 2012." Patterns of leukemia incidence were less clearly related to shale gas activity. The author expressed caution in attributing these trends solely to shale gas development due to "the multiple sources of potentially toxic, harmful exposures in southwest Pennsylvania, many dating back decades," the long latency time required for many cancers to develop, and possible synergisms between exposures from shale gas development and past toxic exposures.

- August 25, 2016 – Researchers found that Pennsylvanians residing near intensive unconventional gas well activity were significantly more likely to experience chronic rhino sinusitis (at least three months of nasal and sinus symptoms), migraine headaches, and higher levels of fatigue than residents who do not live near such activity.[1211] Data were gathered from nearly 8,000 patients of Geisinger Health System from 40 counties in north and central Pennsylvania, and matched with the proximity of respondents to all phases of gas drilling activity and intensity, using information from the Pennsylvania Departments of Environmental Protection (PA DEP) and Conservation and Natural Resources, as well as satellite imagery. According to lead author Aaron W. Tustin, MD, MPH, resident physician in the Department of Environmental Health Sciences at the Johns Hopkins Bloomberg School of Public Health, "[t]hese three health conditions can have debilitating impacts on people's lives… In addition, they cost the health care system a lot of money."[1212]

- July 18, 2016 – Living near fracking operations significantly increases asthma attacks, according to a Johns Hopkins University study of 35,000 medical records of people with asthma in north and central Pennsylvania, from 2005 to 2012.[1213] The data show that those who live near a higher number of, or larger, active gas wells were 1.5 to 4 times more likely to suffer from asthma attacks compared to those who live farther away, with

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[1209] Lisa M. McKenzie et al., "Childhood Hematologic Cancer and Residential Proximity to Oil and Gas Development," ed. Jaymie Meliker, *PLoS ONE* 12, no. 2 (2017): e0170423, https://doi.org/10.1371/journal.pone.0170423.
[1210] M.L. Finkel, "Shale Gas Development and Cancer Incidence in Southwest Pennsylvania," *Public Health* 141 (2016): 198–206, https://doi.org/10.1016/j.puhe.2016.09.008.
[1211] Aaron W. Tustin et al., "Associations between Unconventional Natural Gas Development and Nasal and Sinus, Migraine Headache, and Fatigue Symptoms in Pennsylvania," *Environmental Health Perspectives* 125, no. 2 (2017): 189–97, https://doi.org/10.1289/EHP281.
[1212] Susan Phillips, "New Study Links Gas Drilling to Migraines, Fatigue and Chronic Sinus Symptoms," *State Impact Pennsylvania*, August 25, 2016, https://stateimpact.npr.org/pennsylvania/2016/08/25/new-study-points-to-association-between-gas-drilling-to-migraines-fatigue-and-chronic-sinus-symptoms/.
[1213] Sara G. Rasmussen et al., "Association Between Unconventional Natural Gas Development in the Marcellus Shale and Asthma Exacerbations," *JAMA Internal Medicine* 176, no. 9 (2016): 1334, https://doi.org/10.1001/jamainternmed.2016.2436.

the closest group having the highest risk. There was increased risk in all three types of exacerbations defined: mild (new oral corticosteroid medication order), moderate (emergency department encounter), or severe (hospitalization). In addition, researchers identified increased risk during all four phases of well development: pad preparation, drilling, stimulation (fracking), and production. The study was praised for its "rigorous research methods," by a scientist not part of the team.[1214]

- July 5, 2016 – Researchers from five universities and the U.S. Geological Survey (USGS) identified a link between exposure to fracking and drilling chemicals and adverse reproductive and developmental outcomes in laboratory mice. The study used 23 oil and gas chemicals in four different concentrations, representing concentrations found in drinking water and groundwater, to higher concentrations found in oil and gas industry wastewater. Offspring of pregnant laboratory mice consuming these mixtures were compared to those that did not. Results suggested "numerous potential threats to fertility and reproductive success … including altered pituitary hormone levels, reproductive organ weights, and disrupted ovarian follicle development." Researchers observed these negative outcomes even in the offspring exposed to the lowest dose of chemicals. Building on previous research showing reduced sperm counts in male offspring, they also reported on "tentative mechanistic information for the observed adverse health effects."[1215]

- February 9, 2016 – An exploratory study of hospitalization rates for three study areas in Queensland, Australia showed rates for specific types of hospital admissions increased more quickly in a coal seam gas study area than in other study areas (a coal mining area and a rural/agricultural area). Coal seam gas is the methane trapped in pores and fractures in underground coal deposits; its exploitation is a form of unconventional natural gas development. A portion of coal seam gas extraction uses fracking. This preliminary study found the strongest link between increased hospitalization rates over time in a coal seam gas area to be for the category of 'Blood/immune' diseases.[1216]

- October 14, 2015 – Using an animal model, an interdisciplinary research team measured the endocrine-disrupting activities of 24 chemicals used and/or produced by oil and gas operations, finding that 23 of them "can activate or inhibit the estrogen, androgen, glucocorticoid, progesterone, and/or thyroid receptors, and mixtures of these chemicals can behave synergistically, additively, or antagonistically." Further, the researchers tested prenatal exposures to the chemicals and found effects on multiple organs, including

[1214] Nicholas Kusnetz, "Increased Asthma Attacks Tied to Exposure to Natural Gas Production," *Inside Climate News*, July 18, 2016, https://insideclimatenews.org/news/18072016/asthma-study-marcellus-shale-pennsylvania-natural-gas-fracking/.
[1215] Christopher D. Kassotis et al., "Adverse Reproductive and Developmental Health Outcomes Following Prenatal Exposure to a Hydraulic Fracturing Chemical Mixture in Female C57Bl/6 Mice," *Endocrinology* 157, no. 9 (2016): 3469–81, https://doi.org/10.1210/en.2016-1242.
[1216] Angela K. Werner et al., "All-Age Hospitalization Rates in Coal Seam Gas Areas in Queensland, Australia, 1995–2011," *BMC Public Health* 16, no. 1 (2015): 125, https://doi.org/10.1186/s12889-016-2787-5.

adverse reproductive effects on the matured offspring.[1217] This study is the first to demonstrate that endocrine-disrupting chemicals, which are commonly used in fracking operations, can harm the reproductive health of mice, at levels of exposure that are realistic for humans. The study's senior author told *ScienceDaily,* "In addition to reduced sperm counts, the male mice exposed to the mixture of chemicals had elevated levels of testosterone in their blood and larger testicles. These findings may have implications for the fertility of men living in regions with dense oil and/or natural gas production."[1218]

- October 8, 2015 – Pregnant women who live near active fracking operations in Pennsylvania were at a 40 percent increased risk of giving birth prematurely and at a 30 percent increased risk for having obstetrician-labeled high-risk pregnancies, according to a study by Johns Hopkins Bloomberg School of Public Health and other researchers. High-risk pregnancies were those that included hypertension, high pre-pregnancy body mass index, and asthma. The study used data from the Geisinger Health System on 9,384 pregnant women and their 10,496 newborns between January 2009 and January 2013; Geisinger covers 40 counties in north and central Pennsylvania. Researchers developed an index for proximity to fracking wells based on distance from the women's homes, stage of drilling and depth of wells dug, and the amount of gas that was produced at those wells during the pregnancies. The highest-activity quartile had the highest rates of premature births and high-risk pregnancies.[1219, 1220]

- July 22, 2015 – Using a mammal model, New York University School of Medicine scientists, together with other U.S. and Chinese researchers, demonstrated cancerous changes linked to exposure to wastewater from Marcellus fracking operations. Their study also documented elevated levels of barium and strontium in exposed animal cells. The wastewater studied originated in Pennsylvania and was stored for a time to allow radioactivity and levels of short-lived VOCs to decline. The results suggest that "even aged flow back water could pose substantial health threats to exposed humans."[1221]

- July 15, 2015 – A study by University of Pennsylvania and Columbia University researchers found that drilling and fracking activity was associated with increased rates of hospitalization in Pennsylvania. During a period of dramatic increase in drilling and fracking activity between 2007 and 2011, inpatient prevalence rates surged for people living near shale gas wells. Cardiology inpatient prevalence rates were significantly associated with number of wells per zip code and their density, while neurology inpatient

[1217] Christopher D. Kassotis et al., "Endocrine-Disrupting Activity of Hydraulic Fracturing Chemicals and Adverse Health Outcomes After Prenatal Exposure in Male Mice," *Endocrinology* 156, no. 12 (2015): 4458–73, https://doi.org/10.1210/en.2015-1375.
[1218] Endocrine Society, "Fracking Chemicals Tied to Reduced Sperm Count in Mice," *ScienceDaily*, October 14, 2015, https://www.sciencedaily.com/releases/2015/10/151014134533.htm.
[1219] Joan A. Casey et al., "Unconventional Natural Gas Development and Birth Outcomes in Pennsylvania, USA," *Epidemiology* 27, no. 2 (2015): 163–72, https://doi.org/10.1097/EDE.0000000000000387.
[1220] Johns Hopkins Bloomberg School of Public Health, "Study: Fracking Industry Wells Associated With Premature Birth," October 8, 2015, https://publichealth.jhu.edu/2015/study-fracking-industry-wells-associated-with-premature-birth.
[1221] Yixin Yao et al., "Malignant Human Cell Transformation of Marcellus Shale Gas Drilling Flow Back Water," *Toxicology and Applied Pharmacology* 288, no. 1 (2015): 121–30, https://doi.org/10.1016/j.taap.2015.07.011.

prevalence rates were significantly associated with density of wells. Hospitalizations for cancer, skin conditions, and urological problems also rose significantly. During the same time period, no such increase in health problems was observed in a control Pennsylvania county without any drilling and fracking activity. In communities with the most wells, the rate of cardiology hospitalizations was 27 percent higher than in control communities with no fracking. "While the clinical significance of the association remains to be shown, [fracking] has just begun in Pennsylvania, and thus observing a significant association over this short time is striking.… Our study also supports the concept that health care utilization should be factored into the value (costs and benefits) of hydraulic fracturing over time."[1222] In a related *Newsweek* story, lead researcher Reynold Panettieri, Jr. said, "At this point, we suspect that residents are exposed to many toxicants, noise and social stressors due to hydraulic fracturing near their homes and this may add to the increased number of hospitalizations."[1223]

- July 9, 2015 – As part of a scientific assessment of well stimulation treatments, including fracking, the California Council on Science and Technology studied the potential impacts of well stimulation on human health in California. The risk factors directly attributable to well stimulation stem largely from the use of a very large number and quantity of stimulation chemicals. The unknown number and toxicity of chemicals that are mixed together in well stimulation fluids made it difficult to fully quantify risk to the environment and to human health, but the study highlighted the potential health risks from exposure to fracking-related air pollution for the people of Los Angeles, 1.7 million of whom live or work within one mile of an active oil or gas well.[1224] Jane Long, co-author, said, "officials should fully understand the toxicity and environmental profiles of all chemicals before allowing them to be used in California's oil operations," according to the *Los Angeles Times*.[1225]

- June 22, 2015 – A longtime midwife reported her personal analysis of an ongoing spike in infant deaths, miscarriages, and placental abnormalities in Utah's Uintah Basin that has followed the advent of drilling and fracking activity there and appears linked to air pollution episodes.[1226]

- June 3, 2015 – A University of Pittsburgh study linked fracking to low birthweight in three heavily drilled Pennsylvania counties. The more exposure a pregnant woman had to gas wells, the higher her risk for a smaller-than-normal baby. Exposure was determined as proximity and density of wells in relation to the residence of the pregnant woman. Compared to mothers whose homes had the fewest surrounding gas wells, mothers whose

[1222] Thomas Jemielita et al., "Unconventional Gas and Oil Drilling Is Associated with Increased Hospital Utilization Rates," ed. Jaymie Meliker, *PLoS ONE* 10, no. 7 (2015): e0131093, https://doi.org/10.1371/journal.pone.0131093.
[1223] Zoë Schlanger, "Living Near Fracking Wells Linked to Increased Hospitalization Rates," Newsweek, July 15, 2015, https://www.newsweek.com/living-near-fracking-wells-linked-increased-hospitalization-rates-354093.
[1224] Shonkoff et al., "Chapter 6: Potential Impacts of Well Stimulation on Human Health in California."
[1225] Julie Cart, "Water and Wildlife May Be at Risk from Fracking's Toxic Chemicals, Panel Finds," *Los Angeles Times*, July 10, 2015, sec. California, https://www.latimes.com/local/lanow/la-me-california-science-panel-warns-that-fracking-poses-unknown-risk-20150709-story.html.
[1226] Paul Solotaroff, "What's Killing the Babies of Vernal, Utah?," *Rolling Stone*, June 22, 2015, https://www.rollingstone.com/culture/culture-news/whats-killing-the-babies-of-vernal-utah-33666/.

homes were nearest to a high density of wells were 34 percent more likely to have babies who were "small for gestational age," meaning they weighed significantly less than expected for the number of weeks of pregnancy. Although the study did not investigate mechanisms, researchers identified air as the likely route of exposure. They supported this argument by referencing another study done in Western Pennsylvania where airborne particulate pollution correlated with low birth weight and by noting that particulates are established shale gas infrastructure emissions.[1227, 1228] Low birth weight is a leading cause of infant mortality.

- March 3, 2015 – A follow-up study of 21 case studies from five states found that the distribution of symptoms in animals and humans affected by nearby fracking operations was, since 2012, unchanged for humans and companion animals. In food animals, reproductive problems decreased over time while respiratory problems and growth problems increased. "This longitudinal case study illustrates the importance of obtaining detailed epidemiological data on the long-term health effects of multiple chemical exposures and multiple routes of exposure that are characteristic of the environmental impacts of unconventional drilling operations."[1229]

- March 3, 2015 – A cross-sectional study by Yale University School of Medicine researchers using companion animals as sentinels of human exposure to fracking-related chemicals investigated possible associations between reported health conditions of companion and backyard animals in Southwest Pennsylvania and household proximity to drilling and fracking operations. Among dogs living in households located less than one kilometer from a gas well, risks for health problems were elevated, especially for dermal conditions, compared to animals living more than two kilometers from a well.[1230]

- January 1, 2015 – A Yale-led team studied the relationship between household proximity to drilling and fracking operations and reported health symptoms in Washington County, Pennsylvania where 624 gas wells were in active operation, most of which had been drilled in the past five to six years. Researchers found that health symptoms reported by residents increased in frequency as distance between household and gas wells decreased. Among persons living less than one kilometer from drilling and fracking operations, rashes and upper respiratory problems were more prevalent. The authors of this study, the largest to date on the link between reported symptoms and natural gas drilling activities, say that their findings are "… consistent with earlier reports of respiratory and dermal conditions in persons living near natural gas wells." They also cite literature

[1227] Shaina L. Stacy et al., "Perinatal Outcomes and Unconventional Natural Gas Operations in Southwest Pennsylvania," ed. Jaymie Meliker, *PLoS ONE* 10, no. 6 (2015): e0126425, https://doi.org/10.1371/journal.pone.0126425.
[1228] Robert Preidt, "'Fracking' Linked to Low Birth Weight Babies," WebMD, accessed September 17, 2021, https://www.webmd.com/baby/news/20150603/fracking-linked-to-low-birth-weight-babies.
[1229] Michelle Bamberger and Robert E. Oswald, "Long-Term Impacts of Unconventional Drilling Operations on Human and Animal Health," *Journal of Environmental Science and Health, Part A* 50, no. 5 (2015): 447–59, https://doi.org/10.1080/10934529.2015.992655.
[1230] I. B. Slizovskiy et al., "Reported Health Conditions in Animals Residing near Natural Gas Wells in Southwestern Pennsylvania," *Journal of Environmental Science and Health, Part A* 50, no. 5 (2015): 473–81, https://doi.org/10.1080/10934529.2015.992666.

demonstrating the biological plausibility of a link between oil and gas extraction activities and both categories of health effects reported.[1231]

- December 17, 2014 – As part of a lengthy review that became the foundation for New York State's ban on high volume hydraulic fracturing, the New York State Department of Health (NYS DOH) identified environmental problems associated with fracking that could contribute to adverse public health impacts. Among them: air pollution (particulate matter, ozone, diesel exhaust, and VOCs) that could affect respiratory health; drinking water contamination from underground migration of methane and/or fracking chemicals associated with faulty well construction or seismic activity; drinking water contamination from inadequate water treatment of fracking waste or from surface spills of fracking chemicals or wastewater; earthquakes and the creation of fissures; increased vehicle traffic; increased noise; increased demand for housing and medical care; and public health problems related to climate change impacts from methane and other greenhouse gas emissions into the atmosphere. The NYS DOH Public Health Review also discussed findings from surveys of health symptoms among residents living near high volume hydraulic fracturing activities. These included skin rash, nausea or vomiting, abdominal pain, breathing difficulties, cough, nosebleed, anxiety, stress, headache, dizziness, eye irritation, and throat irritation in populations living near drilling and fracking operations. The NYS DOH Public Health Review noted that ongoing studies by both government agencies and several academic institutions were exploring the public health risks and impacts of fracking but that many of these studies were years from completion. The review concludes:

  > … significant gaps exist in the knowledge of potential public health impacts from [high volume hydraulic fracturing]…. The existing science investigating associations between [high volume hydraulic fracturing] activities and observable adverse health outcomes is very sparse and the studies that have been published have significant scientific limitations. Nevertheless, studies are suggestive of potential public health risks related to [high volume hydraulic fracturing] activity that warrant further careful evaluation.

  In an accompanying letter to the New York State Department of Environmental Conservation, Health Commissioner Howard Zucker, MD, concluded,

  > … the overall weight of the evidence from the cumulative body of information contained in this Public Health Review demonstrates that there are significant uncertainties about the kinds of adverse health outcomes that may be associated with [high volume hydraulic fracturing], the likelihood of the occurrence of adverse health outcomes and the effectiveness of some of the mitigation measures in reducing or preventing environmental impacts which could adversely affect public health. Until the science provides sufficient information to determine the level of risk to public health from [fracking] to all New Yorkers and whether the

[1231] Peter M. Rabinowitz et al., "Proximity to Natural Gas Wells and Reported Health Status: Results of a Household Survey in Washington County, Pennsylvania," *Environmental Health Perspectives* 123, no. 1 (2015): 21–26, https://doi.org/10.1289/ehp.1307732.

risks can be adequately managed, DOH recommends that high volume hydraulic fracturing should not proceed in NYS.[1232]

- October 13, 2014 – According to the North Dakota Health Department, the number of HIV and AIDS cases in North Dakota more than doubled between 2012 and 2014, and cases were shifting to the state's western oil fields, where 35-40 percent of all new cases occurred. Previously, only 10 percent of cases were in that region.[1233] This trend followed on the heels of an upsurge in sexually transmitted chlamydia cases in the same region. The North Dakota state director of disease control, Kirby Kruger, attributed the uptick in HIV cases to the drilling and fracking industry and attempted to spread HIV prevention messages at the "man camps" that house young male workers in the oil industry.[1234] Human trafficking for purposes of prostitution accompanied the fracking boom, but there was a shortage of medical professionals to address this public health crisis, according to Kruger, who noted that it was difficult to hire nurses and medical staff who could live in the area on a public health wage.

- October 2, 2014 – According to researchers from the University of Pennsylvania's Center of Excellence in Environmental Toxicology, an increasing number of gas wells in Pennsylvania is significantly correlated with inpatient rates of hospitalization. The research team collected data from seven different insurance providers for three counties; the study's publication is forthcoming.[1235]

- September 11, 2014 – In Texas, commercial vehicle accidents have increased more than 50 percent since 2009 when the state's ongoing drilling and fracking boom began, according to an investigation by the *Houston Chronicle* and Houston Public Media News 88.7. "For six decades, highway deaths have dropped steadily all across the United States…. But in Texas all motor vehicle fatalities – and accidents involving commercial trucks – have turned back upward since the state's oil drilling and fracking boom began in 2008." This rising motor vehicle death toll is especially felt in formerly rural counties in the Eagle Ford and Permian Basin, now places of heavy drilling and fracking. A new Department of Public Safety "Road Check" program finds annually, "27 to 30 percent of Texas' commercial trucks shouldn't be operating at all due to potentially life-threatening

[1232] New York State Department of Health, "A Public Health Review of High Volume Hydraulic Fracturing for Shale Gas Development," December 17, 2014, http://www.health.ny.gov/press/reports/docs/high_volume_hydraulic_fracturing.pdf.
[1233] Associated Press, "North Dakota HIV/AIDS Rate Rises with Population Growth," *The Billings Gazette*, October 13, 2014, https://billingsgazette.com/news/state-and-regional/montana/north-dakota-hiv-aids-rate-rises-with-population-growth/article_a939fed6-f737-5cfb-957f-ab800673f4d7.html.
[1234] Andy Birkey, "Around the Region: HIV Rates Skyrocket in North Dakota," *The Column*, October 6, 2014, http://thecolu.mn/13773/around-region-hiv-rates-skyrocket-north-dakota.
[1235] Elizabeth Skrapits, "Study: More Gas Wells in Area Leads to More Hospitalizations," *Wilkes-Barre Citizens' Voice*, accessed September 17, 2021, https://www.citizensvoice.com/news/study-more-gas-wells-in-area-leads-to-more-hospitalizations/article_31eec203-76fc-5b9e-9a8a-f4a552bdd4f6.html.

safety problems like defective brakes, bald tires, inoperable safety lights and unqualified, unfit or intoxicated drivers."[1236, 1237]

- August 3, 2014 – Hospitals in the Bakken Shale region reported a sharp rise in ambulance calls and emergency room visits after 2006. "Mercy Medical Center in Williston and the Tioga Medical Center in neighboring Williams County saw their ambulance runs increase by more than 200 percent. Tioga's hospital saw a staggering leap in trauma patients by 1,125 percent. Mercy had a 373 percent increase." Drugs (including overdoses of prescription drugs, methamphetamine, and heroin) explain many of the cases, with oilfield related injuries such as "fingers crushed or cut off, extremity injuries, burns and pressure burns" accounting for 50 percent of the cases in one of the region's hospital emergency rooms.[1238]

- May 21, 2014 – Raising questions about possible links to worsening air pollution from the Uintah Basin's 11,200 oil and gas wells, health professionals reported that infant deaths in Vernal, Utah, rose to six times the normal rate over the past three years. Physician Brian Moench said, "We know that pregnant women who breathe more air pollution have much higher rates of virtually every adverse pregnancy outcome that exists…. And we know that this particular town is the center of an oil and gas boom that's been going on for the past five or six years and has uniquely high particulate matter and high ozone."[1239] Although it formerly had pristine air quality, Uintah County, Utah received a grade "F" for ozone in the American Lung Association's 2013 State of the Air Report.[1240]

- January 28, 2014 – Congenital heart defects, and possibly neural tube defects in newborns, were associated with the density and proximity of natural gas wells within a 10-mile radius of mothers' residences in a study of almost 25,000 births from 1996 to 2009 in rural Colorado. The researchers note that natural gas development emits several chemicals known to increase risk of birth defects (teratogens).[1241]

- January 4, 2014 – Preliminary data from researchers at Princeton University, Columbia University, and MIT showed elevated rates of low birthweight among infants born to mothers living near drilling and fracking operations during their pregnancies.[1242]

[1236] Lise Olsen, "Fatal Truck Accidents Have Spiked during Texas' Ongoing Fracking and Drilling Boom," *Houston Chronicle*, September 11, 2014, sec. News, https://www.houstonchronicle.com/news/article/Fracking-and-hydraulic-drilling-have-brought-a-5747432.php.
[1237] Andrew Schneider, "In Texas, Traffic Deaths Climb Amid Fracking Boom," *NPR*, October 12, 2014, sec. National, https://www.npr.org/2014/10/02/352980756/in-texas-traffic-deaths-climb-amid-fracking-boom.
[1238] K. J. Bryan, "Drugs, Oilfield Work, Traffic Pushing More People through Doors of Watford City ER," *Bakken Today*, August 3, 2014, http://www.bakkentoday.com/event/article/id/37101/.
[1239] Zoë Schlanger, "In Utah Boom Town, a Spike in Infant Deaths Raises Questions," *Newsweek*, May 21, 2014, https://www.newsweek.com/2014/05/30/utah-boom-town-spike-infant-deaths-raises-questions-251605.html.
[1240] American Lung Association, "American Lung Association State of the Air 2013," 2013.
[1241] Lisa M. McKenzie et al., "Birth Outcomes and Maternal Residential Proximity to Natural Gas Development in Rural Colorado," *Environmental Health Perspectives* 122, no. 4 (2014): 412–17, https://doi.org/10.1289/ehp.1306722.
[1242] Mark Whitehouse, "Study Shows Fracking Is Bad for Babies," *Bloomberg*, January 4, 2014, https://www.bloomberg.com/opinion/articles/2014-01-04/study-shows-fracking-is-bad-for-babies.

- August 26, 2013 – Medical experts at a rural clinic in heavily-drilled Washington County, Pennsylvania reported case studies of 20 individuals with acute symptoms consistent with exposure to air contaminants known to be emitted from local fracking operations.[1243, 1244]

- May 2, 2013 – A community-based participatory research study in Pennsylvania tested air and water quality and surveyed self-reported health symptoms of more than 100 residents living near drilling and fracking operations. The team detected a total of 19 VOCs in ambient air sampled outside of homes. The reported health symptoms closely matched the established effects of chemicals detected through air and water testing at those nearby sites. Moreover, those symptoms occurred at significantly higher rates in households closer to the gas facilities than those farther away.[1245] Indicative of the growing prevalence of such health impacts in the state, a poll showed that two-thirds of Pennsylvanians support a moratorium on fracking because of concern about negative health impacts.[1246]

[1243] Lindsay Abrams, "Fracking's Real Health Risk May Be from Air Pollution," *Salon*, August 26, 2013, sec. News, https://www.salon.com/2013/08/26/frackings_real_health_risk_may_be_from_air_pollution/.
[1244] Larysa Dyrszka, Kathleen Nolan, and Sandra Steingraber, "Statement on Preliminary Findings from the Southwest Pennsylvania Environmental Health Project Study," Press Release (Concerned Health Professionals of NY, August 27, 2013), https://concernedhealthny.org/2013/08/statement-on-preliminary-findings-from-the-southwest-pennsylvania-environmental-health-project-study/.
[1245] Nadia Steinzor, Wilma Subra, and Lisa Sumi, "Investigating Links between Shale Gas Development and Health Impacts through a Community Survey Project in Pennsylvania," *New Solutions: A Journal of Environmental and Occupational Health Policy* 23, no. 1 (2013): 55–83, https://doi.org/10.2190/NS.23.1.e.
[1246] Susan Phillips, "Poll Shows Support for a Drilling Moratorium in Pennsylvania," *State Impact Pennsylvania*, May 14, 2013, https://stateimpact.npr.org/pennsylvania/2013/05/14/poll-shows-support-for-a-drilling-moratorium-in-pennsylvania/.

Noise pollution, light pollution, and stress

Drilling and fracking operations and ancillary infrastructure expose workers and nearby residents to continuous noise and light pollution that is sustained for periods lasting many months. Chronic exposure to light at night is linked to adverse health effects, including breast cancer.

Sources of fracking-related noise pollution include blasting, drilling, flaring, generators, compressor stations, and truck traffic. Noise-mitigating sound barriers do not always resolve complaints of nearby residents. Exposure to environmental noise pollution is linked to cardiovascular disease, cognitive impairment, and sleep disturbance. In Colorado, noise measured during construction and drilling of a large, multi-well pad in a residential area exceeded levels knowns to increase the risk of cardiovascular diseases and hypertension.

Denton, Texas residents reported increased levels of stress and anxiety compared to periods of time prior to the arrival of drilling fracking in their community. In rural Canada, residents living near drilling and fracking operations experienced community upheaval and showed multiple signs of trauma. Oil and gas production noise may be disrupting wildlife health in protected areas. Workers and residents whose homes, schools, and workplaces are in close proximity to well sites are at risk from these exposures as well as from related stressors. Existing "setback distances" may not be adequate to reduce public health threats, especially for vulnerable populations. A UK Health Impact Assessment (HIA) identified stress and anxiety resulting from drilling-related noise—as well as from a sense of uncertainty about the future and eroded public trust—as key public health risks related to fracking operations. These results are corroborated by research in the United States showing links between fracking-related stress, lower self-reported health, a sense of helplessness, and distrust in regulatory agencies.

- May 5, 2021 – Induced earthquakes linked to gas extraction and related activities have caused structural damage to housing in the Netherlands. Using previously validated health measures, the first study to address the long-term, stress-related effects on residents experiencing this kind of property damage found evidence of negative health impacts over time. Self-rated health, mental health, and other stress-related health impacts were all greater in a study group of people who had experienced this kind of damage to their homes when compared to a control group whose members did not. These negative impacts increased over time. Those whose homes had repeated damage were 1.60 times more likely to report poor health, 2.11 times more likely to report negative mental health, and 2.84 times more at risk of elevated stress-related health symptoms. The study population was drawn from 25,000 residents of Groningen, Netherlands from a complete registry of all legal residents, and the resulting groups completed questionnaires at five time-points over two years. These findings, the researchers concluded, "suggest that for chronic disasters/hazards, negative effects can accumulate over time, presumably

because the recurrent threat and poor crisis response leads to an accumulation of stress."[1247]

- January 19, 2021 – Drilling and fracking significantly increased light pollution in rural areas of the United States from 2000 to 2012, while in these same areas, residents experienced increased levels of insufficient sleep, according to a study that found a dose-response relationship between the number of horizontal wells and measures of insufficient sleep. Residents in counties with more than 100 wells were three percentage points more likely to report insufficient sleep, and six percentage points more likely to report sleep fewer than seven hours sleep per night. Light pollution has established links to human health: disruptions to melatonin levels and circadian rhythm are linked with mood regulation, depression and sleeping disorders, in addition to metabolic disease and cancer. This study also found that, in areas that had minimal light pollution prior to the shale gas boom, drilling increased the dispersion of nighttime lights by over 100 percent. Urging further research on light pollution from the shale gas industry, authors note that many drilling and fracking operations are sited within International Dark Sky Places where work practices continue around the clock and are dependent on intense artificial lighting and gas flaring.[1248]

- March 14, 2020 – Living in a community with extensive fracking was linked with lower self-rated health, according to an interdisciplinary research team.[1249] The team designed and carried out survey research with three northern Colorado communities with different historical and current levels of fracking: Greeley, Fort Collins, and Windsor. Self-rated health, the researchers explained, has been used successfully across multiple disciplines in thousands of studies. Research has shown there is a strong link between self-rated health and actual health status. Living in Greeley, surrounded by some 21,000 active drilling locations in 2015-2016 when the study was carried out, was associated with lower self-rated health compared to Fort Collins, which voted for a (subsequently overturned) ban on fracking, and has little drilling in the community. Perceived stress from fracking was also linked to lower self-rated health. A third finding was that trust in regulatory agencies improved self-rated health. Authors noted, "Recalling that people in our study who reported the least satisfaction with their health were low-income and also experiencing stress from [unconventional oil and gas extraction], we may see links to environmental injustice and specifically procedural inequity, regarding people's (lack of) control over their local environment and their perceived health impacts."

- March 4, 2020 – More than 300 residents filed noise complaints about new fracking activity near Broomfield, Colorado's northeast side, between fall 2019 and publication of

[1247] Katherine Stroebe et al., "Chronic Disaster Impact: The Long-Term Psychological and Physical Health Consequences of Housing Damage Due to Induced Earthquakes," *BMJ Open* 11 (2021), https://doi.org/10.1136/bmjopen-2020-040710.
[1248] Andrew Boslett, Elaine Hill, and Lujia Zhang, "Rural Light Pollution from Shale Gas Development and Associated Sleep and Subjective Well-Being," *Resource and Energy Economics* 64 (2021), https://doi.org/10.1016/j.reseneeco.2021.101220.
[1249] Adam Mayer et al., "Understanding Self-Rated Health and Unconventional Oil and Gas Development in Three Colorado Communities," *Society & Natural Resources* 34, no. 1 (2020): 60–81, https://doi.org/10.1080/08941920.2020.1734702.

this *KUNC* piece.[1250] The radio station obtained the information through a public records request, finding the community had not gotten relief, despite an overnight noise ordinance that went into effect in late January: "…the noise drones on, according to resident complaints." A municipal judge was, at time of publication, determining whether the new ordinance applied to the oil and gas operator responsible for the noise, as the company maintained they were in compliance with a previous agreement.

- February 13, 2020 – Residents of Denton, Texas reported increased stress and anxiety compared to periods of time prior to the introduction of fracking in the area.[1251] Defining "socio-psychological health" as "one's well-being pertaining to dimensions of both their mental (including emotional) and social health," the researchers sought to build on previous research identifying socio-psychological impacts from fracking, through in-depth, semi-structured interviews. Specific socio-psychological features of participants' experiences included concerns about the environmental health of the community, increased prevalence of personal ailments and physical disorders, and feelings of helplessness linked to lack of response from government officials. Areas where study results were mixed included optimism versus pessimism, and various measures of social cohesion. On the one hand, the "us versus them" construct was a common theme, and on the other, the participants, who were recruited via a town hall meeting, also reported instances of community members brought closer together through their concern and activism.

- January 15, 2020 – The Broomfield, Colorado, City Council "unanimously approved an emergency noise ordinance that will return the onus to a person or company to prove noise generated during restricted hours is below Broomfield's decibel standards."[1252] The ordinance does not specifically address the oil and gas industry but followed a spike in noise complaints from residents near an 18 gas well site. Hundreds of complaints included specific health symptoms that residents linked to the noise, including headaches, difficulty sleeping, and anxiety and stress.

- December 12, 2019 – The City of Broomfield, Colorado issued a statement reacting to the breaching of noise standards by an oil and gas company operating in the city. "We hear you, we acknowledge the impact and we are taking the steps to pursue all legal options to keep our community safe… Our residents are enduring continuous impacts which now includes disturbing noise, sometimes in the middle of the night. Immediate action is necessary," said City and County Manager Jennifer Hoffman addressing city

[1250] Matt Bloom, "Broomfield Tried Limiting Oil And Gas Noise. Now A Company Is Pushing Back," *KUNC*, March 4, 2020, sec. Oil and Gas, https://www.kunc.org/oil-and-gas/2020-03-04/broomfield-tried-limiting-oil-and-gas-noise-now-a-company-is-pushing-back.
[1251] Mehmet Soyer, Kylen Kaminski, and Sebahattin Ziyanak, "Socio-Psychological Impacts of Hydraulic Fracturing on Community Health and Well-Being," *International Journal of Environmental Research and Public Health* 13, no. 17 (2020): 1186, https://doi.org/10.3390/ijerph17041186.
[1252] Jennifer Rios, "Broomfield Passes Emergency Noise Ordinance," *Broomfield Enterprise*, January 15, 2020, https://www.broomfieldenterprise.com/2020/01/15/broomfield-passes-emergency-noise-ordinance-oil-and-gas/.

residents in the press release.[1253] The City received over 35 official noise complaints and verified that there were over 80 noise level readings above the established thresholds in the previous two-week period.

- September 16, 2019 – Residents of Brooke County, West Virginia expressed dissatisfaction with "sound walls" put up to mitigate noise surrounding a local gas well pad. "Residents say one thing that is particularly concerning is the hours that the noise is most bothersome; when they are trying to sleep. It is affecting their sleep and in turn, their health."[1254] The company responsible, Southwestern Energy, stated that noise was not exceeding the levels set by county ordinance and that it would "continue to monitor the situation and work with elected officials."

- May 28, 2019 – Noise levels exceeded World Health Organization guidelines for two types of measurements, A-weighted and C-weighted noise, at four residences in Weld County, Colorado, during all four unconventional oil and gas development phases at a nearby 22-well pad with "sound walls" in place.[1255] This study also included air pollution and truck traffic measurements, finding the highest pollution levels (particulate matter and black carbon) and the greatest number of heavy trucks trip per hour during the fracking phase of operations. During daytime hours on weekdays, one of these measures at one of the four residential sites exceeded the guideline for A-weighted decibels at least 73 percent of the time for each well development phase, drilling, fracking, flowback, and production. During "the high impact phases" of drilling, fracking, and flowback, the second guideline, for C-weighted noise, was exceeded 65 more than half of the time "regardless of whether it was a weekday/weekend or a daytime/nighttime," except at one of the sites. Authors wrote, "The cumulative health effects from multiple stressors for individuals living near these facilities is not known. Furthermore, excessive noise levels and increased truck traffic during the night, when people are home and trying to sleep, could have compounding effects on health and quality of life."

- April 24, 2019 – Northern Colorado communities experienced disturbance including vibration from "massive thumper trucks doing seismic exploration" for the best sites to drill.[1256] One community member said, "Actually made me gasp because it was shaking so loudly… I've felt earthquakes in California and I would say it was similar to that." The company did not provide notification to the targeted neighborhoods until the Colorado Oil and Gas Conservation Commission sent a cease-and-desist letter. After

[1253] Jennifer Hoffman, "Broomfield Notifies Extraction Oil and Gas That It Has Breached Its Operator Agreement by Exceeding Noise Standards," Press Release (City of Broomfield, Colorado, December 12, 2019), https://docs.google.com/document/d/1R2qrVSwPls5bI8dKhZ4GG5OrFia76TwGlC09P_JMD1o/mobilebasic?urp=gmail_link.
[1254] Julianna Furfari, "Residents Fed Up With Fracking Noise Push for Change," *WTOV9*, September 16, 2019, https://wtov9.com/news/local/residents-fed-up-with-fracking-noise-push-for-change.
[1255] William B. Allshouse et al., "Community Noise and Air Pollution Exposure During the Development of a Multi-Well Oil and Gas Pad," *Environmental Science & Technology* 53, no. 12 (2019): 7126–35, https://doi.org/10.1021/acs.est.9b00052.
[1256] Jennifer Kovaleski, "Oil and Gas 'Thumping Trucks' Rattle Colorado Homeowners," *TheDenverChannel.Com*, April 24, 2019, https://www.thedenverchannel.com/news/contact7/oil-and-gas-thumping-trucks-rattle-colorado-homeowners.

complying with notification requirements, the company was allowed to move forward with the estimated four to six weeks of exploration.

- October 8, 2018 – Researchers collected noise measurements from residential areas, inside and outside homes, near two different gas well pads and a compressor station, north and south of Pittsburgh, Pennsylvania. Measurements from all of the outside areas had at least some decibel levels exceeding the recommended limits of the U.S. Environmental Protection Agency (EPA), and one indoor measurement near the compressor station exceeded the recommended level for noise measured inside homes. An accompanying survey documented that 96 percent of respondents were "worried about their overall health as a result of the noise." Fifty-seven percent were bothered "a great deal" by the noise, and slightly more than half of respondents said that their sleep was disturbed "a great deal" by the noise.[1257]

- October 4, 2018 – In the month following one or more earthquakes greater than magnitude 4 experienced in an Oklahoma county, motor vehicle crashes increased 4.6 percent. Anxiety-inducing life events increase the risk of motor vehicle crashes, and earthquakes are known to increase anxiety. University of California, Berkeley public health researchers used data on Oklahoma earthquakes between 2010 and 2016, known to have drastically increased in the state due to fracking wastewater injection, and county-level monthly vehicle crash counts. Authors noted "the high economic and social costs of such vehicle crashes," which were $2.9 billion in Oklahoma in 2010.[1258]

- May 30, 2018 – Anxiety-related Google searches increased 5.8 percent during months when there was more than one magnitude 4 or higher earthquake experienced in Oklahoma, from January 2010 to May 2017. Google searches for anxiety peaked three weeks after magnitude 4 or higher quakes, University of California, Berkeley public health researchers found. Oil and gas wastewater injection has dramatically increased seismicity in Oklahoma; in the study period, there were 8,908 earthquakes across the state of Oklahoma, an average of 218 earthquakes per month. Authors noted, "excessive anxiety… may disable individuals and has long-term implications for health and functioning," and that "excessive symptoms of anxiety occur more readily in response to a recurrent and unpredictable stressor, such as the Oklahoma earthquakes included in our study."[1259]

- May 11, 2018 – Over 40 percent of daytime and 23.6 percent of nighttime audible noise measurements taken during construction and drilling of a large, multi-well pad in a residential area were found to exceed the level that research has demonstrated to increase

[1257] Cynthia M. Richburg and Jeremy Slagley, "Noise Concerns of Residents Living in Close Proximity to Hydraulic Fracturing Sites in Southwest Pennsylvania," *Public Health Nursing* 36, no. 1 (2018): 3–10, https://doi.org/10.1111/phn.12540.
[1258] Joan A. Casey et al., "Increased Motor Vehicle Crashes Following Induced Earthquakes in Oklahoma, USA," *Science of the Total Environment* 10, no. 650 (Part 2) (2019): 2974–79, https://doi.org/10.1016/j.scitotenv.2018.10.043.
[1259] Joan A. Casey, Sidra Goldman-Mellor, and Ralph Catalano, "Association between Oklahoma Earthquakes and Anxiety-Related Google Search Episodes," *Environmental Epidemiology* 2, no. 2 (2018): e016, https://doi.org/10.1097/EE9.0000000000000016.

the risk of health effects, such as cardiovascular diseases and hypertension. When the researchers used an additional measurement that captures low frequency noise levels, these results showed that 97.5 percent of daytime and 98.3 percent of nighttime measurements exceeded the level "recommended to minimize impacts such as nausea and headaches." The measurements collected during this study were from four locations, over three months, in residential areas with oil and gas development in Colorado. Researchers concluded that the distances from the well pad at which some of their measurements were taken, highlight "that homes in closer proximity to operations will likely experience noise exposure at levels of concern even with the implementation of sound mitigation best management practices."[1260]

- December 29, 2017 – Every participant reported experiencing effects in one or more of five categories—psychological stress, social stress, environment, physical health, and traffic—in a study of how residents of two adjacent counties in Ohio are impacted by unconventional natural gas development. Most respondents reported impacts in three or more of the five categories. Types of psychological stress reported included general stress and uncertainty about the future; feeling frustrated and manipulated after interactions with the oil and gas industry; experiencing stress from noise or light pollution; and regional displacement. Researchers found that experiences of social stress extended to include divisions among family or community; fears of, or direct experiences of, environmental health harms; observing dying, unhealthy trees; and traffic-related effects. Nearly all residents interviewed had experienced dangerous encounters with oil and gas truck drivers and observed that damaged roads had become increasingly common.[1261]

- July 28, 2017 – A Canadian case study of the social impacts of fracking in a conservative, upper middle class, rural region of southern Alberta found that residents experienced "complete upheaval in their beliefs, and for many, their experiences with contamination, and fears of future exposure, dominate their lives."[1262] Participants described acute impacts to their own health, to family members' health, to their livestock (including fertility problems), and to their land (included disrupted crop production and abrupt changes to the landscape). The study further reported that authorities failed to respond, "in a manner expected by the victims" to these problems. In addition, "corrosion of community" occurred at a time when victims needed community support the most. The author posited, following a consideration of the literature on toxic contamination and trauma, that her interviewees had experienced the three key indications of trauma: loss of agency, hyperarousal, and ontological insecurity linked to the negative effects on normal daily routines, a sense of order and continuity, and human dignity. The author noted that

[1260] Benjamin D. Blair et al., "Residential Noise From Nearby Oil and Gas Well Construction and Drilling," *Journal of Exposure Science & Environmental Epidemiology* 28 (2018): 538–47, https://doi.org/10.1038/s41370-018-0039-8.
[1261] Michael P. Fisher et al., "Psychosocial Implications of Unconventional Natural Gas Development: Quality of Life in Ohio's Guernsey and Noble Counties," *Journal of Environmental Psychology* 55 (2018): 90–98, https://doi.org/10.1016/j.jenvp.2017.12.008.
[1262] Debra J. Davidson, "Evaluating the Effects of Living With Contamination From the Lens of Trauma: A Case Study of Fracking Development in Alberta, Canada," *Environmental Sociology* 48, no. 2 (2017): 196–209, https://doi.org/10.1080/23251042.2017.1349638.

the contamination experienced by the interviewees reflected a "new normal of non-conventional fossil fuel industries."

- May 5, 2017 – Oil and gas production was one of the main anthropogenic noise sources (though the proportion for which it was responsible was not determined) in a study that quantified the degree and extent of noise pollution in U.S. protected areas (PAs) and critical habitat for endangered species. Authors "compared noise pollution among land management and protection status and investigated sources responsible for generating noise across PAs." The team of biologists and engineers found that human-caused noise doubled background sound in 63 percent of U.S. protected areas, and produced a tenfold or greater increase in 21 percent of protected areas. These levels are "known to interfere with human visitor experience and disrupt wildlife behavior, fitness, and community composition." Researchers also found a 10-fold increase in sound levels in 14 percent of critical habitats of endangered species.[1263]

- April 3, 2017 – A University of Maryland team conducted a pilot study of noise pollution at eight homes located less than a half mile (750 meters) from natural gas compressor stations in West Virginia and compared decibel levels to those collected from homes located further away. They found that daytime and nighttime noise levels were higher at properties located closer to a compressor, as measured both inside and outside the homes. Five of six homes that were monitored for a full 24-hour period had combined day-night indoor average noise levels that exceed 60 decibels (dBA), which exceeds both EPA's recommended limits for chronic noise exposure as well those recommended by the World Health Organization. To date, no federal noise standards exist for oil and gas operations. Noting that noise exposure has been associated in previous studies with sleep disruption, poor academic performance, and hypertension, the authors conclude, "Findings indicate that living near natural gas compressor stations could potentially result in high environmental noise exposures. Larger studies are needed to confirm these findings and evaluate potential health impacts and protections measures."[1264]

- December 9, 2016 – A review analyzing the relevant scientific literature on the potential public health impacts of ambient noise related to unconventional oil and gas development found that "oil and gas activities produce noise at levels that may increase the risk of adverse health outcomes, including annoyance, sleep disturbance, and cardiovascular disease." The team of environmental and occupational health scientists collected available measurements of noise levels at oil and gas operations and analyzed the data with established noise standards. Authors stated that many noise sources from fracking operations are similar to those of conventional oil and gas development, but that high-volume hydraulic fracturing activities present additional noise risks. These arise from conditions including four to five times the length of time needed to drill the well, and the much greater volume of water and higher pressures needed, compared to a traditional vertical well. They described the complexity of noise associated with oil and gas

[1263] Rachel T. Buxton et al., "Noise Pollution Is Pervasive in U.S. Protected Areas," *Science* 356, no. 6337 (2017): 531–33, https://doi.org/10.1126/science.aah4783.
[1264] Meleah D. Boyle et al., "A Pilot Study to Assess Residential Noise Exposure Near Natural Gas Compressor Stations," *PLoS ONE* 12, no. 4 (2017): e0174310, https://doi.org/10.1371/journal.pone.0174310.

operations, including both intermittent and continuous noise, varying in intensities. The review included focus on vulnerable populations, including children, the elderly, and the chronically ill. Authors noted that existing "setback distances" – already often the result of political compromise and not evidence-based – may be insufficient to reduce public health threats, and that maximum allowable noise levels should be lower for schools and hospitals.[1265]

- July 9, 2015 – As part of its assessment of potential health impacts, the California Council of Science and Technology looked at the impacts of noise and light pollution from oil and gas operations in California. The researchers noted that a number of activities associated with drilling and fracking generated noise at levels considered dangerous to public health. Noise is a biological stressor that can aggravate or contribute to the development of hypertension and heart problems. In California, noise from well stimulation was associated with both sleep disturbance and cardiovascular disease in a dose-response relationship. Exposure to artificial light at night has been linked to breast cancer in women, although almost no research has been conducted on the public health implications of light pollution from oil and gas extraction specifically.[1266]

- December 17, 2014 – The New York State Department of Health (NYS DOH) identified community impacts related to noise as a potential contributor to a variety of negative health impacts from drilling and fracking operations but noted that considerable scientific uncertainty remains on the issue of noise exposure per se as a risk factor. Noise, air pollution, traffic, vibration, odors, and nighttime lighting may all increase together as proximity to a drilling site decreases.[1267]

- December 1, 2014 – Range Resources Corporation warned supervisors in Pennsylvania's Donegal Township that a "big burn" natural gas flare will continue for as long as a week and "will produce a continuous noise of as much as 95 decibels at the well pad. Sustained decibel levels between 90 and 95 can result in permanent hearing loss, but workers will be equipped with ear protection." Township supervisor Doug Teagarden expressed concern for residents, saying, "They told us the flare would be double the size of other well flares, and the noise will be like a siren on a firetruck…. There are houses within a couple of hundred yards of the well pad, and those folks are going to hear it."[1268]

- November 6, 2014 – Sakthi Karunanithi, Director of Public Health in Lancashire, UK, reported on a Health Impact Assessment (HIA) of the two proposed shale gas exploration sites in Lancashire. Karunanithi's study determined that key risks to the health and well-being of the residents who live near the two proposed sites in Lancashire include stress

[1265] Jake Hays, Michael McCawley, and Seth B. C. Shonkoff, "Public Health Implications of Environmental Noise Associated With Unconventional Oil and Gas Development," *Science of the Total Environment* 580 (2017): 448–56, https://doi.org/10.1016/j.scitotenv.2016.11.118.
[1266] Shonkoff et al., "Chapter 6: Potential Impacts of Well Stimulation on Human Health in California."
[1267] New York State Department of Health, "A Public Health Review of High Volume Hydraulic Fracturing for Shale Gas Development."
[1268] Don Hopey, "Gas Flare to Light up Part of Washington County," *Pittsburgh Post-Gazette*, December 1, 2014, http://powersource.post-gazette.com/powersource/companies-powersource/2014/12/01/Gas-flare-to-light-up-part-of-Washington-County/stories/201411250224.

and anxiety from uncertainty that could lead to "poor mental wellbeing," and noise-related health effects due to continuous drilling. The HIA also noted a lack of public trust and confidence.[1269, 1270]

- September 2014 – The Ohio Shale Country Listening Project, a collaborative effort to solicit, summarize, and share the perspectives and observations of those directly experiencing the shale gas build out in eastern Ohio, found that the more shale gas wells a community has, the less popular the oil and gas industry becomes. Many residents reported that they had not experienced the economic benefits promised by the oil and gas industry. They complained of increased rents and costs of gas and groceries, an influx of out-of-state workers, more vehicular accidents, road destruction from large trucks, and damaged landscape and cropland. Locals reported feeling less secure and more financially strapped.[1271]

- June 20, 2014 – In its discussion of "Oil and Gas Drilling/Development Impacts," the U.S. Office of Indian Energy and Economic Development detailed noise pollution from bulldozers, drill rigs, diesel engines, vehicular traffic, blasting, and flaring of gas. "If noise-producing activities occur near a residential area, noise levels from blasting, drilling, and other activities could exceed the U.S. Environmental Protection Agency (EPA) guidelines. The movement of heavy vehicles and drilling could result in frequent-to-continuous noise…. Drilling noise would occur continuously for 24 hours per day for one to two months or more depending on the depth of the formation."[1272] Exposure to chronic noise can be deadly. The World Health Organization has documented the connection between environmental noise and health effects, including cardiovascular disease, cognitive impairment, sleep disturbance, and tinnitus. At least one million "healthy life years" are lost every year from traffic-related noise in the western part of Europe.[1273]

- February 24, 2014 – In a review of the health effects from unconventional gas extraction published in the journal *Environmental Science & Technology*, leading researchers noted, "Noise exposure is a significant hazard due to the presence of multiple sources, including

[1269] Sakthi Karunanithi, "Potential Health Impacts of the Proposed Shale Gas Exploration Sites in Lancashire" (Item 9 on the Agenda, Report of the Director of Public Health, Lancashire County Council Cabinet, 2:00 pm in Cabinet Room "B" County Hall, Preston,Lancashire County, UK, November 6, 2014), ://council.lancashire.gov.uk/documents/b11435/Potential%20Health%20Impacts%20of%20the%20Proposed%20Shale%20Gas%20Exploration%20Sites%20in%20Lancashire%2006th-Nov-2014%2014.pdf?T=9.
[1270] Elaine Dunkley, "Fracking in Lancashire 'May Affect Mental Health', Report Finds," *BBC News*, November 7, 2014, sec. Lancashire, http://www.bbc.com/news/uk-england-lancashire-29944212.
[1271] Ohio Organizing Collaborative (OOC)'s Communities United for Responsible Energy (CURE), with support from the Ohio Environmental Council (OEC), FracTracker.org, and Laborers Local 809 of Steubenville, "Ohio Shale Country Listening Project," September 2014, https://web.archive.org/web/20150206015846/http://carrollconcernedcitizens.org/uploads/2014_Shale_Report__small_.pdf.
[1272] Office of Indian Energy and Economic Development, "Oil and Gas Drilling/Development Impacts," Tribal Energy and Environmental Information Clearinghouse, 2014, https://web.archive.org/web/20141008163453/http://teeic.indianaffairs.gov/er/oilgas/impact/drilldev/index.htm.
[1273] Guénaël R. M. Rodier, "Burden of Disease From Environmental Noise: Quantification of Healthy Life Years Lost in Europe" (WHO, June 1, 2011), https://www.euro.who.int/__data/assets/pdf_file/0008/136466/e94888.pdf.

heavy equipment, compressors, and diesel powered generators. Loud continuous noise has health effects in working populations. It is likely that exposure to noise is substantial for many workers, and this is potentially important for health because drilling and servicing operations are exempt from some sections of the Occupational Safety and Health Administration noise standard." They noted that research should investigate stressors such as noise and light in the context of drilling and fracking operations in order to understand the overall effect of chemical and physical stressors together.[1274]

- May 30, 2014 – The *Denver Post* reported that in order to help meet Colorado's noise limits for fracking operations in suburban neighborhoods (and partially block the glare of floodlights), Encana Oil and Gas erected 4-inch-thick polyvinyl walls up to 32 feet high and 800 feet long. Residents said that the plastic walls do not completely solve the problem.[1275]

- October 25, 2013 – An analysis of well location and census data by the *Wall Street Journal* revealed that at least 15.3 million Americans now live within a mile of a well that has been drilled since 2000. According to this investigation, the fracking boom has ushered in "unprecedented industrialization" of communities across wide swaths of the nation and, with it, "24/7" industrial noise, stadium lighting, earth-moving equipment, and truck traffic.[1276]

- April 16, 2013 – In a presentation on oil field light pollution for a conference on "Sustainable Environment and Energy: Searching for Synergies," Roland Dechesne of the Royal Astronomical Society of Canada described problems of "light trespass," glare, and poorly-aimed fixtures in oil fields in Alberta. He described resulting "mass waterfowl mortality" linked to artificial illumination and other biochemical impacts of light pollution on wildlife, as well as the possibility of these effects on humans, including circadian disruption, melatonin suppression, and possible resulting hormonally-linked diseases.[1277] Known to have ecological impacts, outdoor light pollution from drilling and fracking operations may also be linked to artificial light-associated health effects documented in humans, including breast cancer.[1278]

- April 2013 – Led by the University of Pittsburgh Graduate School of Public Health, a study of community members living in proximity to Marcellus Shale drilling in Pennsylvania found adverse impacts to mental health, with stress the most frequently reported symptom. At least half of all respondents in each set of interviews reported these

[1274] John L. Adgate, Bernard D. Goldstein, and Lisa M. McKenzie, "Potential Public Health Hazards, Exposures and Health Effects from Unconventional Natural Gas Development," *Environmental Science & Technology* 48, no. 15 (2014): 8307–20, https://doi.org/10.1021/es404621d.
[1275] Bruce Finley, "Oil and Gas Industry Building Giant Walls to Try to Ease Impact," *The Denver Post*, May 29, 2014, sec. Environment, http://www.denverpost.com/ci_25859469/oil-and-gas-industry-building-giant-walls-try.
[1276] Russell Gold and Tom McGinty, "Energy Boom Puts Wells in America's Backyards," *The Wall Street Journal*, October 25, 2013, http://online.wsj.com/news/articles/SB10001424052702303672404579149432365326304.
[1277] Roland Dechesne, "Limiting Oil Field Light Pollution for Safety and the Environment," in *Sustainable Environment and Energy CPANS 2013 Conference*, 2013.
[1278] Ron Chepesiuk, "Missing the Dark: Health Effects of Light Pollution," *Environmental Health Perspectives* 117, no. 1 (2009): A20–27, https://doi.org/10.1289/ehp.117-a20.

specific stressors, including: being taken advantage of; health concerns; concerns/complaints ignored; corruption; denied information or provided with false information. Many also reported the desire to move or leave community, estrangement from community, and financial damages. Researchers noted that stress can result in direct health impacts.[1279] Notably, mounting evidence indicates that chronic stress magnifies individuals' susceptibility to effects of pollution; for children, this interactive effect can begin during prenatal life.[1280]

- September 7, 2011 – A study by researchers at Boise State University and Colorado State University at Fort Collins modeled the potential impacts of compressor station noise from oil and gas operations on Mesa Verde National Park in Colorado. The study found the sound of 64 compressors outside Mesa Verde elevated the sound level within the park by 34.8 decibels on average, and by 56.8 decibels on the side of the park located closest to the compressors. According to the EPA, 55 decibels is the highest "safe noise level" to avoid damage to the human ear.[1281]

[1279] Kyle J. Ferrar et al., "Assessment and Longitudinal Analysis of Health Impacts and Stressors Perceived to Result From Unconventional Shale Gas Development in the Marcellus Shale Region," *International Journal of Occupational and Environmental Health* 19, no. 2 (2013): 104–12, https://doi.org/10.1179/2049396713Y.0000000024.
[1280] Catherine M. Cooney, "Stress–Pollution Interactions: An Emerging Issue in Children's Health Research," *Environmental Health Perspectives* 119, no. 10 (2011): a430–35, https://doi.org/10.1289/ehp.119-a430.
[1281] Jesse R. Barger et al., "Anthropogenic Noise Exposure in Protected Natural Areas: Estimating the Scale of Ecological Consequences," *Landscape Ecology* 26 (2011): 1281, https://doi.org/10.1007/s10980-011-9646-7.

Earthquakes and seismic activity

Increasing numbers of studies from the United States, Canada, China, and the United Kingdom show that both fracking and the underground disposal of fracking wastewater is definitively linked to earthquakes. In 2019, the United Kingdom declared a moratorium on fracking after an agency report on fracking-related earthquakes in Lancashire concluded that it was not possible to predict their likelihood or size in ways that could prevent them from occurring. This moratorium is still in place.

Definitive evidence from Ohio, Arkansas, Texas, Oklahoma, Kansas, and Colorado links fracking wastewater disposal wells to earthquakes of magnitudes as high as 5.8, in addition to swarms of minor earthquakes. Between 2017 and 2020, the number of earthquakes linked to fracking wastewater injection more than tripled in Oklahoma, Texas, Louisiana, and New Mexico.

Recent research has clarified the mechanisms by which fracking and the injection of fracking waste may trigger earthquakes. Fracking wastewater injection into shallow geological zones increases pressures within the pore spaces of rock layers and may lead to the unclamping of stressed geological faults, including within deeper faults located several miles below the surface. The act of fracking itself takes place in deeper geological formations than injection of fracking waste. Recent research shows that fracking activities can trigger earthquakes both near and far from the well pad by increasing fault zone permeability. Fracking can also cause long-dormant faults to slip in ways that can damage wells through shearing forces. Even small fault slips and imperceptible microquakes caused by fracking can deform well casings, according to the results of a 2022 study. The impact of induced earthquakes on well leakage is not well understood. The question of what to do with fracking wastewater remains a problem with no viable, safe solution.

Emerging evidence suggests that the frequency of fracking-induced earthquakes can continue to rise for years after waste injection, that these earthquakes can take place at distances far from the site of waste injections, and that earthquake risks cannot be prevented through "proper" fracking protocols or by solely limiting the rate or volume of injected fluid. In Canada, elevated earthquake activity in heavily fracked regions continued during a period of industry quiescence brought on by the COVID-19 pandemic.

Emerging evidence suggests that the injection of supercritical carbon dioxide in fracking operations may also be linked to earthquake risk.

- May 29, 2023 – Combining a wide variety of imaging and analytic approaches, researchers in China investigated the cause of four recent moderately large earthquakes in an area that had been previously seismically quiescent and was recently and intensively fracked. Their proposed model, which employs readily available and increasingly common technological tools, encourages prospective evaluations of proposed industrial sites for "geological susceptibility" and explicitly calls for operators to be "more conservative" near susceptible regions: "The conservativeness in operations may include reducing injection volumes, lowering the injection pressures, shortening horizontal wells,

restricting the thresholds for the traffic light protocol [guidelines for interrupting or ceasing hydraulic fracturing or wastewater disposal activities], or their combinations." This structure-based susceptibility evaluation approach, the authors contend, can be used to avoid inducing damaging earthquakes from fracking operations.[1282]

- March 23, 2023 – On November 30, 2022, the town of Peace River experienced the largest (ML5.6) earthquakes ever recorded in the Canadian province of Alberta. Although the Alberta Energy Regulator initially judged this a natural tectonic event, researchers employing a broad range of imaging and analytic methods concluded that the earthquake occurred due to underground wastewater disposal from nearby fracking operations. By resampling seismic data to improve accuracy, determining subsurface fault planes and origins of seismic activity, and using InSAR geodetic modeling to depict surface deformations temporally related to industrial activities, the researchers showed human activities were the most plausible explanation of the earthquake. The new study argues that the injected wastewater, by being forced into a deep geological fault, reduced the friction holding the two sides together in ways that allowed them to slip past each other and trigger an earthquake. This study highlights the need for rigorous assessments of causality and raises concerns also about subsurface injections of carbon dioxide, which has been proposed as a potential climate mitigation strategy. The authors note that the industrial-scale injection of carbon dioxide into deep sedimentary formations carries similar risks of inducing earthquakes as wastewater disposal. Earthquakes of these magnitudes can be deadly, if they occur in populated areas.[1283]

- December 14, 2022 – A research team investigated a possible link between induced earthquakes from fracking operations and healthcare visits for anxiety disorders in Oklahoma between 2010 and 2019. By correlating earthquake activity in Oklahoma with anxiety-related health care visits recorded in a large de-identified database of Medicare Advantage claims, researchers identified a statistically significant increase in health care visits coded as stress disorders for every five felt earthquakes (defined as earthquakes of Moment Magnitude greater than or equal to 4) in the preceding six months. The psychiatric diagnosis of stress disorder relates to traumatic events and includes features such as anxiety, intense fear, or helplessness, dissociative symptoms, and avoidant behaviors. Because the vast majority of mental health needs go unmet, this study likely underestimates the number of people experiencing trauma secondary to experiencing earthquakes induced by hydraulic fracturing activities, including wastewater injection. The researchers note that related studies with Oklahoma residents indicate "an overall sense of resentment towards induced earthquakes [and their costs]." The results of this study are supported by prior studies in Oklahoma that have documented an increase in motor vehicle crashes and in online searches related to anxiety that were both correlated

[1282] Junlun Li et al., "High Seismic Velocity Structures Control Moderate to Strong Induced Earthquake Behaviors by Shale Gas Development," *Communications Earth & Environment* 4, no. 1 (May 29, 2023): 188, https://doi.org/10.1038/s43247-023-00854-x.
[1283] Ryan Schultz et al., "Disposal From In Situ Bitumen Recovery Induced the ML Peace River Earthquake," *Geophysical Research Letters* 50, no. 6 (March 28, 2023): e2023GL102940, https://doi.org/10.1029/2023GL102940.

with felt earthquakes. These represent indirect indicators of harms to human populations from fracking-related induced earthquake activity.[1284]

- November 10, 2022 – An assessment of ground deformation and seismicity in two areas of intense fracking activity in the Argentinian Patagonian Plateau correlated ground movements, as measured with Satellite Synthetic Aperture Radar Interferometry and records of hydraulic fracturing, fluid extraction, and fluid injection, along with historic and current seismic records. The researchers concluded that correlations exist between the onset of hydraulic fracturing activities and large magnitude earthquakes, as well as surface deformations (and inferred subsurface fault planes). Available data do not allow a determination as to whether water extractions or injections of fluids during hydraulic fracturing play a more dominant role in triggering induced earthquakes in the region.[1285]

- April 25, 2022 – Employing a dense array of seismic stations in an intensely fracked area marked by recent large earthquakes, researchers in Weiyuan, China used a variety of new computerized analytic methods to characterize complex subsurface fault systems that they conclude "are reactivated by hydraulic fracturing." They also found that, by increasing fault zone permeability, fracking can trigger earthquakes far from the well pad, "hence increasing the potential seismic hazard associated with injection-induced earthquakes in this and other regions around the world." Because Chinese regulations require that all wastewater from hydraulic fracturing is collected, purified, and then reused, underground wastewater injection could be ruled out as a cause of the earthquake activity documented in the study.[1286]

- February 7, 2022 – Slippage on subsurface faults occurs at rates ranging along a continuum from "creep to supershear earthquakes." Slow slip events are known to be important in releasing stress, delaying or preventing abrupt radiations of damaging seismic energy. However, these kinds of aseismic shifts can sometimes increase stress in unstable zones, leading to dynamic rupture. To clarify the role of slow-slip events in fault activation and earthquake generation related to hydraulic fracturing, a team of researchers in Canada used Interferometric synthetic-aperture radar to study an area near Calgary that is well-monitored by seismic networks. Despite an absence of detected seismicity, radar imagery revealed "consistent patterns of paired uplift and subsidence," indicative of shear dislocations on faults (i.e., aseismic slow slip events) at shallow depths near the underground injection interval targeted by fracking. In other words, the data revealed that the largest fracking-induced earthquake in Canada, to date, is the result of a slow-slip event. Researchers documented that these events also correlated with concurrent reports of deformations in the steel casings of fracked wells in the areas that were of sufficient magnitude to lodge equipment in the wellbore and interrupt fracking activities. Noting

[1284] Holly Elser et al., "Manmade Earthquakes and Healthcare Visits for Anxiety Disorders in Oklahoma, 2010–2019," *Environmental Epidemiology* 7, no. 1 (February 2023), https://doi.org/10.1097/EE9.0000000000000232.
[1285] Guillermo Tamburini-Beliveau et al., "Assessment of Ground Deformation and Seismicity in Two Areas of Intense Hydrocarbon Production in the Argentinian Patagonia," *Scientific Reports* 12, no. 1 (November 10, 2022): 19198, https://doi.org/10.1038/s41598-022-23160-6.
[1286] Minhan Sheng et al., "Earthquakes Triggered by Fluid Diffusion and Boosted by Fault Reactivation in Weiyuan, China Due to Hydraulic Fracturing," *Journal of Geophysical Research: Solid Earth* 127, no. 5 (May 2022), https://doi.org/10.1029/2021JB022963.

that casing deformation is not uncommon during hydraulic fracturing, the researchers conclude that "'thrust belts activated by fluid injection [during hydraulic fracturing] can exhibit a range of slip behavior…, ranging from slow slip events to dynamic rupture." They recommend using radar technology to monitor deformation processes in areas of fluid injection to more accurately characterize earthquake hazards and illuminate links between slow-slip events, casing deformations, and earthquake activity related to hydraulic fracturing.[1287]

- February 1, 2022 – To elucidate the mechanisms driving earthquake activity and surface deformation in the intensely fracked Delaware Basin in Texas, researchers used satellite-based interferometric Synthetic Aperture Radar images coupled with sophisticated modeling and analysis of subsurface data. Building on prior studies that identified local instances of sinking caused by oil, gas, and groundwater extraction and instances of uplift caused by the injection of fracking wastewater, this study provides a detailed model to explain how swaths of land can rise and fall along long, narrow strips as movement-prone, shallow underground faults slip in response to increased fluid pressure. When the fault is activated by fluid injection, the upper block of the fault slides downward along the lower block under the force of gravity. While some fault slippage results in measurable earthquake activity, slippage can sometimes continue in an aseismic fashion for years to decades.[1288] The findings suggest the observed motion on the surface is caused by slip on shallow faults where two blocks of Earth's crust meet along an inclined plane, "like a loaf of bread sliced diagonally."[1289]

- January 27, 2022 – While earthquake induction by fracking-related activities is proven, the responsible mechanisms are still debated as the geological depths from where the earthquakes arise have varied widely. This study sought to resolve the uncertainty around the question of depth. Accurate depth determination can differentiate between earthquakes triggered by fracking wastewater injection, which takes place at comparatively shallow levels, from earthquakes triggered by fracking itself, which takes place in deeper geological zones. A Stanford-led research team studied a small, intensively fracked area within the Delaware Basin in Texas, where 21 perceptible earthquakes had struck within the previous few years. Using two seismic monitoring stations and an "attentive, deep-learning model" (a specialized form of artificial intelligence), researchers were able detect and analyze subtle seismic activity, including hundreds of microquakes centered within the study area as well as thousands of other small quakes that originated from zones farther away. Using three independent but complementary characterizations of subsurface seismicity—seismic velocities; precise location of the depths of origin of identified earthquakes; and modeling of low-frequency body and surface waves in relation to subsurface faults—the researchers determined that fracking wastewater injection, rather than fracking per se, was the cause of the quakes in

[1287] Thomas S. Eyre et al., "InSAR Data Reveal That the Largest Hydraulic Fracturing-Induced Earthquake in Canada, to Date, Is a Slow-Slip Event," *Scientific Reports* 12, no. 1 (February 7, 2022): 2043, https://doi.org/10.1038/s41598-022-06129-3.
[1288] K. S. Pepin et al., "Shallow Aseismic Slip in the Delaware Basin Determined by Sentinel-1 InSAR," *Journal of Geophysical Research: Solid Earth* 127, no. 2 (February 2022), https://doi.org/10.1029/2021JB023157.
[1289] Josie Garthwaite, "Earthquakes from Oil Field Wastewater," *Stanford Earth Matters*, May 19, 2022, https://earth.stanford.edu/news/earthquakes-oil-field-wastewater#gs.3pyoiu.

this particular swath of the Delaware Basin. All three forms of analysis showed that the earthquake activity originated from the shallow geological zone that is used for the disposal of fracking wastewater. Combined with emerging satellite evidence of surface deformation in the same area of the Delaware Basin, these results provide support for the hypothesis that preexisting faults are activated when pore pressures are elevated by wastewater injections. Fracking wastewater disposal is an unavoidable cause of fault slippage.[1290]

- January 7, 2022 – By analyzing the evolution over time of induced seismicity caused by hydraulic fracturing activities, researchers in Alberta discovered two distinct geologic regions and calculated the annual likelihood of large earthquakes (magnitude M > 4) in each region for the period from 2014 to 2020. Despite increasing intensity of hydraulic fracturing activities, the seismic hazard in the Duvernay Play region has declined, possibly due to regulatory restraints and changes in operational practices, including a relative avoidance of earthquake prone areas.[1291]

- October 28, 2021 – To better detect and characterize fracking-induced earthquakes in the Blackpool region of the United Kingdom, researchers used historical data combined with digital template matching (TM) techniques, which extract waveform images of past events and use them as templates to find similar new events. These methods make possible the detection of smaller magnitude earthquakes, the modeling of faults and seismic sources, and better correlation of subsurface events with various stages of hydraulic fracturing activities. This novel application of template matching techniques allows for the study of induced earthquakes in places that lack well-distributed arrays of surface monitoring stations.[1292]

- June 10, 2021 – According to Norwegian energy research firm Rystad Energy, earthquakes attributed to fracking waste disposal in Oklahoma, Texas, Louisiana, and New Mexico more than tripled in frequency over a three-year period. In 2020, 938 earthquakes above magnitude 2.0 were recorded in the region, up from 242 in 2017. This 3.85-fold increase in seismic activity coincides with a period of steadily increasing volumes of wastewater pumped into underground injection wells. Injection volumes in the United States have increased almost 50 percent over the past decade to 11.3 billion barrels last year, more than double the volume of oil that was produced. Some oil companies report recycling the wastewater, for use in additional oil drilling, crop irrigation, or other purposes, but in 2020, only 1.5 billion barrels of wastewater (less than 15 percent of barrels produced) were recycled, according to Rystad. "Around 570 similar induced tremors have been recorded through the first five months of 2021, meaning we

[1290] Yixiao Sheng, Karissa S. Pepin, and William L. Ellsworth, "On the Depth of Earthquakes in the Delaware Basin: A Case Study along the Reeves–Pecos County Line," *The Seismic Record* 2, no. 1 (January 1, 2022): 29–37, https://doi.org/10.1785/0320210048.
[1291] Mauricio Reyes Canales et al., "The Rise, Peak and Decline of the Seismic Hazard Related to Hydraulic Fracturing Activities in the Duvernay Play, Fox Creek Area, Alberta," *Journal of Geophysical Research: Solid Earth* 127, no. 1 (January 2022), https://doi.org/10.1029/2021JB023060.
[1292] Nasim Karamzadeh et al., "Induced Seismicity Due to Hydraulic Fracturing near Blackpool, UK: Source Modeling and Event Detection," *Journal of Seismology* 25, no. 6 (December 2021): 1385–1406, https://doi.org/10.1007/s10950-021-10054-9.

may see a new record this year if the trend continues," the report read. "The trend appears to be moving not only to more frequent, but also larger events."[1293]

- May 26, 2021 – An analysis of trends based on detailed records of 2,865 wells and 439 earthquakes in the Peace River region prompted a former senior scientist with British Columbia's oil and gas commission, Allen Chapman, to predict that induced earthquakes of magnitude 5.0 or greater will very likely occur in the future if current fracking activities in the region continue unabated. In a rebuke of reliance on so-called "traffic light" protocols as a form of earthquake management, Chapman warned that fracking-induced earthquakes of large magnitudes can and do occur without precursor warning and thus represent significant risks to public safety and infrastructure. Noting the likelihood of industry unwillingness to alter their practices due to the necessity of a "high degree of brute force" to hit production goals and financial targets, Chapman recommended the establishment of "frack-free zones proximal to populations and critical infrastructure."[1294]

- May 21, 2021 – A study led by a U.S. Geological Survey (USGS) team determined that the dramatic proliferation of seismic activity near the Permian Basin city of Pecos, Texas since 2000 is likely caused by fracking wastewater disposal practices. This includes a magnitude 5.0 earthquake in March 2020. The team identified more than 45,000 seismic events in the area and compared spatial and temporal data in the earthquake inventory with industrial records. "We identify several cases of hydraulic fracturing induced seismicity…but the vast majority of earthquakes are likely induced by wastewater disposal…in particular injecting at depths greater than 1.5 kilometers."[1295]

- May 17, 2021 – Researchers in the United Kingdom used detailed microseismic data from a single fracking site in Lancashire to conclude that pore pressure increases are the likely mechanism for the earthquakes induced at the site, with "each operation activat[ing] different faults with different orientations." Despite examining a single site in detail with extensive data from prospective monitoring, the researchers stress that establishing the causative processes for induced seismicity is a complex and challenging computational task because multiple physical processes during hydraulic fracturing act in tandem to reactivate faults.[1296]

- May 10, 2021 – Increases in the pressures of fluid within the pores of deep geological strata is commonly invoked as the main driver for induced earthquakes triggered by the injections of fracking wastewater. However, a comprehensive investigation of a surge of

[1293] Ryan Hassler, "Treating the US Oil Industry's Dark Water: As Earthquakes Increase, Billions Needed to Switch Course" (Rystad Energy, June 10, 2021), https://www.rystadenergy.com/newsevents/news/press-releases/treating-the-us-oil-industrys-dark-water-as-earthquakes-increase-billions-needed-to-switch-course/.
[1294] Allan R Chapman, "Hydraulic Fracturing, Cumulative Development and Earthquakes in the Peace River Region of British Columbia, Canada," *Journal of Geoscience and Environment Protection* 9 (2021): 55–82, https://doi.org/10.4236/gep.2021.95006.
[1295] Robert J. Skoumal and Daniel T. Trugman, "The Proliferation of Induced Seismicity in the Permian Basin, Texas," *Journal of Geophysical Research: Solid Earth* 126, no. 6 (2021), https://doi.org/10.1029/2021JB021921.
[1296] Tom Kettlety and James P. Verdon, "Fault Triggering Mechanisms for Hydraulic Fracturing-Induced Seismicity From the Preston New Road, UK Case Study," *Frontiers in Earth Science* 9 (2021), https://doi.org/10.3389/feart.2021.670771.

earthquakes in the Delaware Basin in Texas from 1993 to 2020 revealed that changes in poroelastic stresses that can refer to other hydraulically isolated rock layers, rather than changes in pore pressure per se, can be the dominant stress change that induces earthquakes in some cases. Poroelastic stresses refer to fluid-mediated deformation of solid materials. That is, human activities in shallow geological strata can cause poroelastic stresses that trigger unexpected, unpredictable, and uncontrollable responses in isolated, sometimes distant, tectonic regions, especially if major faults are present, and sometimes after long time delays. "We show that the widespread deep seismicity is mainly driven by shallow wastewater injection through the transmission of poroelastic stresses assuming that unfractured shales are hydraulic barriers over decadal time scales." Relying on industrial, seismic, geodetic, and geological data to develop new, integrated models of induced seismicity led researchers to conclude that "induced seismic hazard can be minimized by injecting fluids into porous sediments rather than a low-porosity basement."[1297]

- April 1, 2021 – A fracking wastewater injection well in Youngstown, Ohio caused a magnitude 4.0 earthquake on December 31, 2011, just prior to ceasing operation. Now abandoned and with no identifiable owner, the 9,200-foot-deep well was ordered sealed two years ago and yet remains open, with the well's former operators in prison and the company charged with plugging the well in bankruptcy.[1298]

- March 31, 2021 – During the early months of the global Covid-19 pandemic, from April to August 2020, fracking and wastewater disposal operations virtually halted in Alberta and northeast British Columbia, yet seismic stations recorded 389 earthquakes in those two Canadian provinces. Researchers observed that seismic events during this period of industry quiescence seem to share many characteristics with seismicity generated during fracking operations. According to their analysis 65 percent of the seismicity detected during the lockdown period is attributable to latent ongoing geological processes related to prior fluid injection. They posit mechanisms such as aseismic slip, with fault and fracture weakening over extended distances, to explain how an elevated background seismicity rate has become the "new normal" with earthquake activity continuing even during a period of temporarily ceased fracking and wastewater disposal activities.[1299]

- March 21, 2021 – Citing research from 2018 demonstrating that injected wastewater can cause sufficient pressure to trigger earthquakes more than 55 miles away [see entry for February 15, 2018 below], regulators in Kansas reversed their original interpretation of the origin of a series of more than a dozen earthquakes occurring in Wichita at the end of 2020. Additional earthquakes in 2021 pointed to injection of wastewater as the likely

[1297] Guang Zhai, Manoochehr Shirzaei, and Michael Manga, "Widespread Deep Seismicity in the Delaware Basin, Texas, Is Mainly Driven by Shallow Wastewater Injection," *PNAS* 118, no. 20 (2021), https://doi.org/10.1073/pnas.2102338118.
[1298] Justin Dennis, "A Quake-Causing Injection Well in Youngstown Remains Unsealed 2 Years After Its Deadline. Here's Why," *Mahoning Matters*, April 1, 2021, https://www.mahoningmatters.com/local-news/a-quake-causing-injection-well-in-youngstown-remains-unsealed-2-years-after-its-deadline-heres-why-3595487.
[1299] Rebecca O. Salvage and David W. Eaton, "Unprecedented Quiescence in Resource Development Area Allows Detection of Long-Lived Latent Seismicity," *Solid Earth* 12 (2021): 765–83, https://doi.org/10.5194/se-12-765-2021.

cause of the earthquake swarm. According to Rick Miller, senior scientist and seismologist at Kansas Geological Survey, the oil and gas industry accounts for a majority of wastewater wells in Kansas, although other industries, such as chemical, petrochemical, and food processing, also dispose of wastewater in underground wells. Which industry is responsible for inducing the large increase in earthquakes in Kansas in 2020 and 2021 remains unknown.[1300]

- November 11, 2020 – An examination of more than 40 years of data from California demonstrated extremely high correlations between oilfield waste injection and the occurrence of earthquakes near the San Andreas Fault. As in Oklahoma, the size of the spatial footprint of induced seismicity is quite large, in California reaching to distances up to 24 kilometers (almost 15 miles). Researchers observed deformation of the surface of the earth in close proximity to the wastewater injection wells, with significant surface uplift.[1301] Separately, a co-author of this study argued that California's natural earthquake activity may have been masking industry-induced quakes.[1302] However, this new research reveals that fluid-injection operations, even though they take place near seismically active, well-known faults in California, are activating smaller unmapped faults and elevating injection-induced seismic hazards. The authors note that injection of waste directly above the geological basement layer, high-rate, broadscale injection into permeable zones, and the presence of tectonically stressed faults are likely all contributing factors and suggest that operators look for more stable regions in which to inject wastewater.

- September 2, 2020 – Seismic hazard risk assessment has until recently focused almost exclusively on risk exposure related to naturally occurring tectonic earthquakes. However, the timing and location of induced earthquakes offer unique opportunities for intervention because they are functions of economic forces as well as public policy decisions. Hence, earthquakes are an environmental justice issue. In Oklahoma, investigators found that induced seismicity disproportionately impacts communities with "low-income, female-headed and African-American households, workers employed in the primary economic sector, and Hispanic populations of employed men." Moreover, vulnerable populations may have decreased ability to participate in the generation of mitigation plans or to choose to move elsewhere. Authors recommend targeting areas of high exposure to earthquake exposures and high social vulnerability for measures to lessen risk, reduce social vulnerability, or both.[1303]

[1300] Sarah Spicer, "State Said Wichita Earthquakes Were Likely Natural. New Evidence Suggests Otherwise," *The Wichita Eagle*, March 21, 2021, https://www.kansas.com/news/politics-government/article250044639.html.
[1301] Thomas H. Goebel and Manoochehr Shirzaei, "More than 40 Yr of Potentially Induced Seismicity Close to the San Andreas Fault in San Ardo, Central California," *Seismological Research Letters* 92, no. 1 (2021): 187–98, https://doi.org/10.1785/0220200276.
[1302] Thomas H. Goebel, "Oil Field Operations Likely Triggered Earthquakes in California a Few Miles From the San Andreas Fault," *The Conversation*, November 10, 2020, https://theconversation.com/oil-field-operations-likely-triggered-earthquakes-in-california-a-few-miles-from-the-san-andreas-fault-149207.
[1303] Sahar Derakhshan, Michael E. Hodgson, and Susan L. Cutter, "Vulnerability of Populations Exposed to Seismic Risk in the State of Oklahoma," *Applied Geography*, 2020, https://doi.org/10.1016/j.apgeog.2020.102295.

- August 5, 2020 – Researchers studied the characteristics of wastewater, particularly pressure, temperature, and composition, to identify whether fluid properties can contribute to the generation of induced seismicity in laboratory simulations. They found that oilfield wastewater with higher concentrations of total dissolved solids than are present in the fluids held within subsurface basement layers can result in density-driven pressure gradients that, along with fracture permeability, contribute to the generation of induced earthquakes. These findings help to explain the observed transfer of high pressure from wastewater injection across long distances (exceeding 10 to15 kilometers, or approximately 6 to 9 miles). In some modeled scenarios, fluid pressure could be expected to increase locally below injection wells for up to 20 years after the end of injections. Injecting high-density brines into geologic formations with "seismogenic" basements (typically characterized by low-density brines) creates conditions that may result in fluid pressure transients sufficient to trigger earthquakes.[1304]

- July 14, 2020 – Geologists in Alberta investigated a swarm of earthquakes that persisted over 10 months following the cessation of fracking activities in western Canada and determined persistent aseismic slip to be the likely primary causative mechanism rather than fluid migration or other mechanisms. Their model posits that increased pore pressure from fracked wells loads faults in unstable regions, causing seismicity with lateral confinement of the creeping region eventually resulting from increased pore pressure. Some swarms (both induced and naturally occurring) previously ascribed to a pore pressure migration model might better be understood as generated by aseismic slip. This model suggests that current mitigation strategies, such as "traffic light protocols," for mitigating induced seismicity caused by fracking may be "sub-optimal" because these protocols "assume that a larger magnitude earthquake is preceded by smaller precursory events, and that changes in operations … have an immediate effect on the source process of induced events." These assumptions are not borne out by current evidence.[1305]

- May 31, 2020 – An analysis of USGS earthquake catalogs for 17 major fracking locations across the United States for the period from 1998 to 2018 shows statistical associations between fracking locations (including wastewater disposal sites) and increased earthquake activity. The association between fracking activities and earthquakes is particularly strong in Texas, Oklahoma, and Kansas.[1306]

- May 7, 2020 – It is not currently possible to confidently forecast the occurrence or maximum size, of a fracking-induced earthquake, nor are retrospective strategies sufficient "to protect critical or vulnerable infrastructure that have unacceptable failure consequences," according to a review published in *Nature Reviews Earth &*

[1304] Ryan M. Pollyea et al., "A New Perspective on the Hydraulics of Oilfield Wastewater Disposal: How PTX Conditions Affect Fluid Pressure Transients That Cause Earthquakes," *Energy & Environmental Science* 13 (2020): 3014–31, https://doi.org/10.1039/D0EE01864C.
[1305] Thomas S. Eyre et al., "A Long-Lived Swarm of Hydraulic Fracturing-Induced Seismicity Provides Evidence for Aseismic Slip," *Bulletin of the Seismological Society of America* 110, no. 5 (2020): 2205–15, https://doi.org/10.1785/0120200107.
[1306] Valeria Villa and Ramesh P. Singh, "Hydraulic Fracturing Operation for Oil and Gas Production and Associated Earthquake Activities Across the USA," *Environmental Earth Sciences* 79 (2020): 271, https://doi.org/10.1007/s12665-020-09008-0.

Environment. The review by three Canadian geoscientists determined that induced earthquakes, once triggered, are similar to their natural counterparts, although their hazards "might greatly exceed the natural earthquake hazard in regions of low to moderate seismicity." "Traffic light protocols," in which fracking operators reduce injection for an amber light or stop injection for a red light in response to predefined thresholds of quakes and population density, have not been successful, according to the review.[1307] Referring to this work, a Canadian investigative report outlined the deficits of British Columbia's practice of limiting fracking only after earthquakes have been triggered, adding to decades-long concern about the troubled Site C dam project in northeastern British Columbia, in a region of increasing earthquakes.[1308] Increasing understanding of the mechanisms by which induced seismicity can destabilize previously stable geologic formations also contributes to concerns about Site C dam. The review states that "it is clear that hazard mitigation, via the use of forecasting models to control the magnitude of the largest possible event, is in its infancy," and cannot, for example, account for the unpredictable nature of fault propagations possibly related to rupture of entire fault plains. Thus, limiting (yellow light) or stopping (red light) fracking activities upon the occurrence of small, induced earthquakes may not prevent future and possibly larger earthquakes from occurring.

- April 21, 2020 – Researchers employed satellite-based InSAR (Interferometric Synthetic Aperture Radar) to monitor surface deformation to study three sites in western Texas. They then correlated observed patterns of deformation with earthquake distributions and other factors to distinguish the causes of deformation. Groundwater withdrawals appear to have played a role in geologic changes, including subsidence, while wastewater injection (disposal) probably played a dominant role at two sites. Similarities and differences at the three studied sites "suggest the importance of local rock structures and properties in determining seismic behavior and sensitivity to injection."[1309]

- March 10, 2020 – Comparing the ground motion and damage potential of naturally occurring and induced earthquakes based on instrumental data and felt reports, a Canadian geologist concluded that both types of seismic activity have "significant damage potential within 10 km [over six miles]," at magnitude 5.0, while events of magnitude 5.5 would have "damage potential to a distance of 20 km [over 12 miles]." Detailing damage from induced earthquakes around the globe, the author noted damage in Oklahoma to brick buildings with accompanying soil liquefaction and slumping; injury to 135 people in Korea, with damage to 57,000 structures; and collapse of houses, landslides, and injuries to 19 people in China. To preclude earthquake damage, the author wrote, hazard mitigation measures must aim to prevent the occurrence of induced

[1307] Gail M. Atkinson, David W. Eaton, and Nadine Igonin, "Developments in Understanding Seismicity Triggered by Hydraulic Fracturing," *Nature Reviews Earth & Environment* 1, no. 5 (2020): 264–77, https://doi.org/10.1038/s43017-020-0049-7.
[1308] Andrew Nikiforuk, "Thousands of Quakes, Tied to Fracking, Keep Shaking the Site C Dam Region," *The Tyee*, August 13, 2020, https://thetyee.ca/News/2020/08/13/Quakes-Fracking-Site-C-Dam-Region/.
[1309] Fanghui Deng, Timothy H. Dixon, and Surui Xie, "Surface Deformation and Induced Seismicity Due to Fluid Injection and Oil and Gas Extraction in Western Texas," *Journal of Geophysical Research: Solid Earth* 125, no. 5 (2020): e2019JB018962, https://doi.org/10.1029/2019JB018962.

earthquakes of magnitude 3.5 or greater within approximately 5 kilometers (3 miles) of vulnerable structures.[1310]

- February 25, 2020 – Scientists used a variety of seismological techniques to conclude with a newly emerging cluster of earthquakes in Alberta, Canada, are "almost certainly" the result of nearby hydraulic fracturing activities.[1311] The largest event ascribed directly to fracking measured magnitude 4.18 ML, believed to have resulted from thrust-slip on a fault underlying the target formation. In March 2019, Alberta introduced a new "traffic light" regulatory framework to interrupt fracking activities associated with earthquakes of increasingly high magnitude.

- January 9, 2020 – BC Hydro, the publicly owned Canadian electric utility in the province of British Columbia, knew for "well over a decade that its Peace Canyon dam is built on weak, unstable rock and that an earthquake triggered by a nearby natural gas industry fracking or disposal well operation could cause the dam to fail." This information, obtained through freedom of information legislation, had not been shared with various relevant governmental entities and panels, nor even a construction manager at the dam. Hundreds of emails, letters, memos and meeting notes documented concerns discussed at the highest levels, and that the utility's dam safety specialist wrote "email after email to his superiors expressing fear about how encroaching fracking operations could destabilize BC Hydro's Peace Canyon dams."[1312]

- December 14, 2019 – Researchers used improved catalogs of earthquake activity and multistation template matching to determine that while the vast majority of earthquakes in western and southern Texas between 2015 and 2018 were associated with wastewater disposal, "at least ~5% of the seismicity was induced directly by hydraulic fracturing." While geologic features may act to influence the occurrence and location of induced seismicity, fracking induced seismicity is pervasive in the neighboring state of Oklahoma, and the researchers suggest that the frequency of earthquakes and the number of earthquakes greater than magnitude 3 will continue to increase if industry operations continue unaltered.[1313]

- November 13, 2019 – Fracking induced 94 earthquakes with a magnitude greater than 2.0 from 2014 through 2018 in the Eagle Ford Shale.[1314] This included what may have been

[1310] Gail M. Atkinson, "The Intensity of Ground Motions from Induced Earthquakes with Implications for Damage Potential," *Bulletin of the Seismological Society of America* 110, no. 5 (2020): 2366–79, https://doi.org/10.1785/0120190166.
[1311] Ryan Schultz and Ruijia Wang, "Newly Emerging Cases of Hydraulic Fracturing Induced Seismicity in the Duvernay East Shale Basin," *Tectonophysics* 779 (2020): 228393, https://doi.org/10.1016/j.tecto.2020.228393.
[1312] Ben Parfitt, "Peace Canyon Dam at Risk of Failure From Fracking-Induced Earthquakes, Documents Reveal," *The Narwhal*, January 9, 2020, https://thenarwhal.ca/peace-canyon-dam-at-risk-of-failure-from-fracking-induced-earthquakes-documents-reveal/.
[1313] Robert J. Skoumal et al., "Induced Seismicity in the Delaware Basin, Texas," *Journal of Geophysical Research: Solid Earth* 125, no. 1 (2019), https://doi.org/10.1029/2019JB018558.
[1314] Shannon L. Fasola et al., "Hydraulic Fracture Injection Strategy Influences the Probability of Earthquakes in the Eagle Ford Shale Play of South Texas," *Geophysical Research Letters* 46, no. 22 (2019): 12958–67, https://doi.org/10.1029/2019GL085167.

the largest fracking-related earthquake in the United States, a magnitude 4.0 quake that occurred near the site of a 4.8 quake that occurred in 2011, thought to be induced by fluid extraction. The research team wrote that their study "demonstrates that faults in this area are capable of producing felt and potentially damaging earthquakes due to ongoing [fracking]." In addition, they proposed that fracking by "simultaneous stimulation of multiple laterals" was three times more to cause earthquakes than a single well strategy.

- November 4, 2019 – Considerably expanding understanding of the history of the Pecos earthquake cluster in west Texas, researchers demonstrated that anomalous earthquakes began in 2009 and increased dramatically, with more than 2,000 earthquakes in 2017. The largest of these had a local magnitude of 3.7, but the overall activity pattern did not rule out future earthquakes of larger magnitude. The team observed that seismic activity, petroleum production, fluid waste injection, and hydrofracturing activity all rose in tandem, suggesting that fracking-related activities may be responsible for inducing this unusual earthquake activity between 2009 and 2017. They did not speculate which specific activities may have led to the onset of the quakes in 2009, nor which of these activities are most responsible for the recent spike in their frequency.[1315]

- November 2, 2019 – The UK government declared a moratorium on fracking after an Oil and Gas Authority (OGA) report concluded that predicting the risk, size, and location of earthquakes linked to fracking operations is not possible. However, it left open the possibility that the temporary ban could be lifted if further scientific discoveries allowed fracking-induced seismicity to be managed.[1316] The OGA's report was based on an assessment of fracking operations taking place at Preston New Road in Lancashire in northwest England. It found that susceptibility to earthquakes depends on local geology but the precise geological characteristics creating that susceptibility are not sufficiently understood to serve as applicable predictors. "Methods for predicting the maximum magnitude that adopt a link between injected volume and the maximum magnitude of induced events lack convincing empirical evidence or proven theoretical basis." After repeated seismic events and a magnitude 2.9 earthquake, fracking operations were suspended at the Preston New Road site in August 2019. The OGA concluded that, based on the pattern of ground motion, the likely cause was a rupture of a previously unidentified strike-slip fault, and the "possibility of larger events could not be excluded."[1317]

- October 14, 2019 – Some earthquakes in west Texas are more likely due to fracking itself than frack waste disposal, according to a team that matched earthquake times and locations with those of fracking activities. A new seismic monitoring program of nearly 60 seismographs created in 2015 resulted in this "improvement in absolute location

[1315] Cliff Frohlich et al., "Onset and Cause of Increased Seismic Activity Near Pecos, West Texas, United States, From Observations at the Lajitas TXAR Seismic Array," *Journal of Geophysical Research: Solid Earth* 125, no. 1 (2019): e2019JB017737, https://doi.org/10.1029/2019JB017737.
[1316] Aonghus Heatley, "UK Government Ends Its Support for Fracking in England (At Least for Now)," *The National Law Review*, November 4, 2019, https://www.natlawreview.com/article/uk-government-ends-its-support-fracking-england-least-now.
[1317] Oil and Gas Authority, "Interim Report of the Scientific Analysis of Data Gathered from Cuadrilla's Operations at Preston New Road," 2019, https://www.ogauthority.co.uk/media/6149/summary-of-pnr1z-interim-reports.pdf.

accuracy."[1318] This study is a first in challenging the view that the induced quakes are only caused by wastewater injection wells rather than the fracking process. The new program, TexNet, is funded by the state of Texas and its research arm, the Center for Integrated Seismicity Research, is funded by the state in partnership with oil and gas companies.[1319]

- August 28, 2019 – The mechanism by which fracking triggers earthquakes is an area of unsettled science. Calling into question earlier studies that ascribe a central role to pore pressure diffusion or poroelastic stress changes as the trigger of earthquakes caused by hydraulic fracturing, researchers from the University of Calgary in Alberta, Canada, instead invoke an alternative model. This team argues that fault activation is caused by progressive loading of distant, unstable regions of a fault by a phenomenon called "aseismic slip," in which displacement along a fault radiates out to a seismogenic area. Noting that key features of the fundamental processes of fault activation remain poorly understood and that so-called "traffic light protocols" rely on the assumptions that smaller seismic events precede large-magnitude earthquakes and that changes in injection operations will have immediate effects, the new model calls for a better characterization of rock properties and faults near fracking and disposal zones.[1320]

- August 26, 2019 – In accordance with a Hydraulic Fracturing Plan with a "traffic light system" modeled after ones used in Canada, fracking operations at the Preston New Road site in Lancashire, England were suspended after multiple earthquakes at the fracking site, including a 2.9 magnitude tremor that was felt at the surface.[1321]

- July 29, 2019 – As a first step in predicting future fracking-related earthquakes more accurately, a model must be able to account for the distribution, frequency, and historical time course of past earthquakes. Researchers using a "physics-based" forecasting model that includes consideration of both pore pressure and poroelastic stresses (the mechanical properties of rocks, such as elastic response to fluid pressures) have been able retroactively to simulate the observed pattern of induced seismicity in Oklahoma, where earthquake activity has increased 900-fold since 2008.[1322] According to the study's lead author, "An interesting finding… was that a tiny change in the rocks' elastic response to changes in fluid pressure can amplify the number of earthquakes by several times. It's a

[1318] Anthony Lomax and Alexandros Savvaidis, "Improving Absolute Earthquake Location in West Texas Using Probabilistic, Proxy Ground-Truth Station Corrections," *Journal of Geophysical Research: Solid Earth* 124, no. 11 (2019): 11447–65, https://doi.org/10.1029/2019JB017727.
[1319] Sergio Chapa, "Study Linking Fracking to Permian Basin Earthquakes Stirs Public Debate," *Houston Chronicle*, October 15, 2019, sec. Energy, https://www.houstonchronicle.com/business/energy/article/Study-linking-fracking-to-Permian-Basin-14537085.php.
[1320] Thomas S. Eyre et al., "The Role of Aseismic Slip in Hydraulic Fracturing-Induced Seismicity," *Science Advances* 5, no. 8 (2019): eaav7172, https://doi.org/10.1126/sciadv.aav7172.
[1321] Oil and Gas Authority, "Hydraulic Fracturing at Preston New Road Suspended," *News*, August 26, 2019, https://www.ogauthority.co.uk/news-publications/news/2019/hydraulic-fracturing-at-preston-new-road-suspended/.
[1322] Guang Zhai et al., "Pore-Pressure Diffusion, Enhanced by Poroelastic Stresses, Controls Induced Seismicity in Oklahoma," *Proceedings of the National Academy of Sciences U.S.A.* 116, no. 33 (2019): 16228–33, https://doi.org/10.1073/pnas.1819225116.

very sensitive factor."[1323] In addition, the model indicates that shutting down injection wells where fracking waste is disposed may not immediately alleviate the probability of large earthquakes as the underground diffusion of fluid continues even after injection stops.

- July 16, 2019 – Because briny oilfield wastewater is more dense than host rock fluids, it will continue to migrate downward long after it is injected into an underground well. Even when injection rates are significantly reduced as a technique to alleviate the risk of earthquakes, sinking wastewater can cause a pressure front to migrate downward at comparable rates. The result is elevated subsurface fluid pressures that persist for more than a decade and increase with depth.[1324] This phenomenon raises the risks for earthquakes of higher magnitude because deeper faults, which are under higher stress, can release more energy when they rupture.[1325] As a consequence, wastewater disposal via underground injection effectively creates a time bomb as the risk of high-magnitude earthquakes may continue to rise even as overall earthquake activity slows.

- May 3, 2019 – Researchers at Tufts University combined field data and modeling data in a study that found that fracking wastewater disposal can trigger earthquakes originating from zones far beyond where the fracking wastewater diffuses. Overturning previous assumptions, these results suggest that waste fluids can activate slippage in faults that then quickly outpaces the spread of fluid underground. That is, a rupture front can develop and accelerate ahead of regional pore-pressure increases caused by migrating fluids and, potentially, activate slippage in distant pre-existing faults. If so, these runaway ruptures might trigger earthquakes of magnitudes greater than predicted based on an assessment of fluid-pressurized volumes.[1326, 1327]

- March 27, 2019 – The USGS deployed additional seismometers in the area around south Alabama and the Florida Panhandle following the detection of five earthquakes in the course of a week. The earthquakes, ranging in magnitude from 2.1 to 3.7, occurred in an area flagged as likely experiencing more seismic activity over the past decade due to oil and gas operations in the area.[1328] In 1997, a series of earthquakes, including the second

[1323] Arizona State University, "Predicting Earthquake Hazards From Wastewater Injection," *Phys.Org*, July 29, 2019, https://phys.org/news/2019-07-earthquake-hazards-wastewater.html.
[1324] Ryan M. Pollyea et al., "High Density Oilfield Wastewater Disposal Causes Deeper, Stronger, and More Persistent Earthquakes," *Nature Communications* 10, no. 3077 (2019), https://doi.org/10.1038/s41467-019-11029-8.
[1325] Anna Kuchment, "Even If Injection of Fracking Wastewater Stops, Quakes Won't," *Scientific American*, September 9, 2019, https://www.scientificamerican.com/article/even-if-injection-of-fracking-wastewater-stops-quakes-wont/.
[1326] Bhattacharya and Viesca, "Fluid-Induced Aseismic Fault Slip Outpaces Pore-Fluid Migration."
[1327] Tufts University, "Study Suggests Earthquakes ARe Triggered Well BEyond Fluid Injection Zones," *AAAS Eureka Alert*, May 2, 2019, https://www.eurekalert.org/pub_releases/2019-05/tu-sse050119.php.
[1328] Dennis Pillion, "Did Fracking Cause South Alabama Earthquakes? Federal Researchers Investigating," *AL.Com*, March 27, 2019, sec. Mobile Real-Time News, https://www.al.com/news/mobile/2019/03/did-fracking-cause-south-alabama-earthquakes-federal-researchers-investigating.html.

largest in Alabama's history (at magnitude 4.9), occurred in the same region and was tentatively linked to oil and gas drilling and two associated injection wells nearby.[1329]

- March 8, 2019 – Over a two-day period in February 2019, three earthquakes struck a farming community in an area of China's Sichuan Province that is experiencing a fracking boom. Two people were killed, 13 injured, 20,000 homes destroyed, and 1,600 people displaced. In response to citizen protests, fracking operations were suspended.[1330]

- March 1, 2019 – A USGS-led team monitored leakage and fluid pressure over time in a permeable bedrock formation used for disposal of fracking waste in Osage County, Oklahoma. By inserting specially designed instruments into an unused disposal well within this formation, the team demonstrated an overall trend of increasing fluid pressure. "The only conceivable source of this increase is due to the injection of wastewater." The results also showed evidence that fracking waste is leaking out of the reservoir where it is being injected "at a significant rate." The direction of the leakage appears mostly downward into the basement rock below. The authors note that disposal of fracking waste is the leading cause of pressure changes on faults in Oklahoma and that fluid pressure changes are, in turn, the leading cause of earthquakes in Oklahoma.[1331]

- December 12, 2018 – For six continuous years, hydraulic fracturing and related activities have triggered multiple earthquakes of varying magnitudes in northwestern Alberta and northeastern British Columbia, with the operations of one company linked to tremors that have jolted Fort St. John from 2012 to 2018.[1332] Between September 2013 and January 2015 alone, researchers in western Alberta, Canada detected than 900 seismic events, ranging in magnitude from 1 to 4. Real-time recordings of seismic activity were generally consistent with published empirical and point-source simulation models. Approximately 80 percent of the events in the compiled database occurred "in distinct clusters in time and space that are characteristic of induced events."[1333] These induced earthquakes pose hazards to roads, pipelines, dams, groundwater, and public safety. Canadian scientists question whether any regulatory system could effectively forecast, control, or prevent them. In some cases, cessation of injection activities following large, potentially damaging earthquakes appears to a sufficient response. However, in other cases, quakes occur months after injection activities, falling outside the windows of immediate intervention that most "traffic light systems" are put in place to address.[1334] Further,

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[1329] Joan Gomberg and Lorraine Wolf, "Possible Cause for an Improbable Earthquake: The 1997 Mw 4.9 Southern Alabama Earthquake and Hydrocarbon REcovery," *Geology* 27, no. 4 (1999): 367–70, https://doi.org/10.1130/0091-7613(1999)027<0367:<PCFAIE>2.3CO;2.
[1330] Myers, "China Experiences a Fracking Boom, and All the Problems That Go with It."
[1331] Andrew J. Barbour et al., "Leakage and Increasing Fluid Pressure Detected in Oklahoma's Wastewater Disposal Reservoir," *Journal of Geophysical Research: Solid Earth* 124, no. 3 (2019): 2896–2919, https://doi.org/10.1029/2019JB017327.
[1332] Andrew Nikiforuk, "Company Linked to Tremors That Jolted Fort St. John Triggered Previous Quakes," *The Tyee*, December 12, 2018, https://thetyee.ca/News/2018/12/12/Fort-St-John-Tremors/.
[1333] Mark Novakovic and Gail M. Atkinson, "Preliminary Evaluation of Ground Motions from Earthquakes in Alberta," *Seismological Research Letters* 86, no. 4 (2015): 1086–95, https://doi.org/10.1785/0220150059.
[1334] Andrew Nikiforuk, "Fracking Linked to Quake That Jolted Fort St. John," *The Tyee*, December 4, 2018, https://thetyee.ca/News/2018/12/04/Fracking-Linked-Quake-Jolted-Fort-St-John/.

companies are allowed to continue their activities despite predictions that considerable seismic activity may result, including earthquakes of much greater magnitude than predicted.[1335]

- November 28, 2018 – Noting that fracking is a microseismic event, a research team investigated whether the activity of hydraulic fracturing itself, and not just the disposal of fracking waste, can trigger earthquakes and might be contributing to the dramatic increases in frequency of seismic events across the central and eastern United States. The team focused on Oklahoma where they identified roughly 700 fracking-induced earthquakes, including 12 with magnitude between 3 and 3.5. Previous reports had described only two fracking-induced earthquakes in Oklahoma. Results also confirmed that, in Oklahoma, proximity of an injection site to a critically stressed fault is a better predictor of induced seismicity than a more commonly accepted general approach based on proximity to the Precambrian basement layer. These results demonstrate that public research provides far greater detail and accuracy than data and notifications voluntarily released by drilling operators.[1336]

- November 11, 2018 – In Lancashire, England, fracking has triggered at least 37 minor earthquakes. Regulations require suspension of fracking activities when seismicity exceeds magnitude 0.5. Energy company Cuadrilla, which had previously supported these limits, lobbied the government to relax the regulations in order to allow fracking to continue. These calls have been rejected by the energy minister.[1337]

- October 31, 2018 – A holistic analysis of fracking waste disposal practices and seismicity compared intensely drilled regions across the United States, including the Bakken, Eagle Ford, and Permian shale basins, as well as basins in Oklahoma. Results showed consistent links between increased seismicity and increased depth of wastewater injection, increased rate of injection, and increased regional injection volumes. Shallower disposal wells help lower the risk of earthquakes. However, they raise the risk of groundwater contamination as increased pressures can push fluids through "faults or fractures or through abandoned oil wells that have not been properly plugged." The researchers also noted that deep waste disposal carries the risk of introducing toxic fluids into karstified areas where there is "limited geologic characterization of the disposal zone." These deep, cave-like zones may transmit fluids in an unknown, unpredictable fashion.[1338]

[1335] Simon Little, "Fort St. John Earthquakes Were Caused by Fracking: BC Oil and Gas Commission," *Global News*, December 22, 2018, sec. Economy, https://globalnews.ca/news/4789210/fort-st-john-frackqing-earthquakes/.
[1336] Robert J. Skoumal et al., "Earthquakes Induced by Hydraulic Fracturing Are Pervasive in Oklahoma," *Journal of Geophysical Research: Solid Earth* 123, no. 12 (2018): 10918–35, https://doi.org/10.1029/2018JB016790.
[1337] Adam Vaughan, "Fracking Firm Boss Says It Didn't Expect to Cause Such Serious Quakes," *The Guardian*, November 11, 2018, https://www.theguardian.com/environment/2018/nov/11/fracking-firm-boss-says-it-didnt-expect-to-cause-such-serious-quakes-lancashire?fbclid=IwAR2BEOJ3ySPm-7WiigVilQQyyjdzqAxOHbZxYGEH4s9RFbObbUfPwKGW9dM.
[1338] Bridget R. Scanlon et al., "Managing Basin-Scale Fluid Budgets to Reduce Injection-Induced Seismicity from the Recent U.S. Shale Oil Revolution," *Seismological Research Letters* 90, no. 1 (2019): 171–82, https://doi.org/10.1785/0220180223.

- August 31, 2018 – To delineate possible mechanisms for the induction of earthquakes at unexpectedly large distances from injection wells, researchers looked at data in the public domain from around the world. They found two patterns. One type of seismicity, manifesting a "direct pressure effect," clusters near wells and tends to be shallow, of modest magnitude, and to decay abruptly. The second type of seismicity, potentially triggered by elastic stresses, tends to occur in deeper layers, decay slowly, and exhibit larger spatial footprints and magnitudes. Both shallow and deep formations present unique risks, and these should be included in mitigation strategies.[1339] With low to moderate-sized human-made earthquakes putting 1 in 50 people in the United States at risk according to a recent USGS analysis, injection practices for oil and gas wastewater are "creating a ripple effect far beyond … drilling locations."[1340]

- April 27, 2018 – The use of fracking to enhance geothermal energy recovery activated two faults in a previously unknown fault system and triggered a magnitude 5.5 earthquake near Pohang, South Korea. Using primarily publicly available data, the researchers characterized the fault dimensions, faulting mechanism, and depth of earthquake activity, which correlated with surface deformation at the time of the earthquake activity. The earthquake's main shock caused extensive structural damage to buildings in and around Pohang and injured 70 people.[1341]

- March 16, 2018 – Utilizing satellite radar imagery, researchers observed and analyzed ground deformation, earthquake activity, and subsidence (depressions and sinkholes) that appear to be the result of "decades of oil activity and its effects on rocks below the earth's surface."[1342, 1343] Noting that West Texas has been "punctured like a pincushion with oil wells and injection wells since the 1940s," the team documented an "alarming rate" of heaving and sinking across a 4,000-square-mile area.[1344] The researchers documented visible surface-level and subsurface changes from fracking, fracking waste injection, carbon dioxide injection that is used to aid in oil and gas exraction, and abandoned and uncapped wells. Some data may help sort out why hazards manifest in one site rather than another. Satellite assessments of deformation can provide crucial safety information to protect roadways, homes, businesses, industrial facilities, pipelines, and people from "potential larger catastrophic events."

[1339] Thomas H. Goebel and Emily Brodsky, "The Spatial Footprint of Injection Wells in a Global Compilation of Induced Earthquake Sequences," *Science* 361, no. 6405 (2018): 899–904, https://doi.org/10.1126/science.aat5449.
[1340] B. Guarino, "How Energy Companies Set Off Earthquakes Miles Away From Their Waste Dumps," *The Washington Post*, August 30, 2018, https://www.washingtonpost.com/science/2018/08/30/how-energies-companies-set-off-earthquakes-miles-away-their-waste-dumps/?utm_term=.ee67ec5d693a.
[1341] F. Grigoli et al., "The November 2017 Mw 5.5 Pohang Earthquake: A Possible Case of Induced Seismicity in South Korea," *Science* 360, no. 6392 (2018): 1003–6, https://doi.org/10.1126/science.aat2010.
[1342] Jin-Woo Kim and Zhong Lu, "Association Between Localized Geohazards in West Texas and Human Activities, Recognized by Sentinel-1A/B Satellite Radar Imagery," *Scientific Reports* 8 (2018): 4727, https://doi.org/10.1038/s41598-018-23143-6.
[1343] Sydney Greene, "Large Portions of West Texas Sinking at Alarming Rate, New Report Finds," *The Texas Tribune*, March 22, 2018, https://www.texastribune.org/2018/03/22/report-says-large-portions-west-texas-counties-are-sinking-alarming-ra/.
[1344] Margaret Allen, "Radar Images Show Large Swath of West Texas Oil Patch Is Heaving and Sinking at Alarming Rates," *SMU Research News*, March 20, 2018, https://blog.smu.edu/research/2018/03/20/radar-images-show-large-swath-of-texas-oil-patch-is-heaving-and-sinking-at-alarming-rates/.

- February 27, 2018 – Since December 2016 in Oklahoma, 74 earthquakes of at least 2.5 magnitude have been linked directly to fracking. As a result, state regulators tightened mitigation protocols and required operators to use seismic arrays to detect underground movement and pause their work when earthquakes exceed magnitude 2.5.[1345] These changes make Oklahoma's new regulations tougher than Canada's, where "the industry holds the record for causing magnitude 4-plus earthquakes by high volume fracking."[1346] Described by industry sources as "a cautious move forward, limiting though not hamstringing [the] oil industry," the new regulations will be evaluated in the field for their effectiveness in reducing the frequency of earthquakes large enough to be felt at the surface.[1347]

- February 20, 2018 – Researchers in Kansas used high-precision data from an extensive seismometer network to detail features of a surge of earthquakes that they concluded were induced by wastewater injection in southern Kansas. Some areas were free from earthquakes, despite injection activities, suggesting that unknown local geological conditions play a role in determining seismic activity. Lack of seismic activity in these areas is "either due to a lack of fluid pathways to the basement [deep geological layer] or due to the absence of faults that are close to failing." Regional influences led to more prolonged seismicity and were observed from wastewater injection wells located 10 or more kilometers away.[1348]

- February 15, 2018 – In Kansas, swarms of earthquakes near oil wastewater disposal wells began in 2013. By 2017, the prodigious volumes of injected fluid created sufficient pressure to trigger earthquakes more than 50 miles away and form a "triggering front" that advanced at an average rate of nearly 10 miles per year along a permeable fault zone.[1349] A mapping project based on gravity loads, magnetic fields, and seismic activity dating to 1979 revealed a previously unidentified subsurface fault running from central Nebraska 200 miles southeast to Kansas.[1350]

- February 5, 2018 – Focusing their investigation on areas in Ohio that are isolated from fracking waste injection activities, researchers found that fracking itself induced earthquakes in two distinct manners. In some cases, earthquake activity occurred in

[1345] Oklahoma Corporation Commission, & Oklahoma Geological Survey, "Moving Forward: New Protocol to Further Address Seismicity in State's Largest Oil and Gas Play," News Release, February 27, 2018, https://oklahoma.gov/content/dam/ok/en/occ/documents/og/02-27-18protocol.pdf.
[1346] Andrew Nikiforuk, "Spooked by Quakes, Oklahoma Toughens Fracking Rules," *The Tyee*, March 9, 2018, https://thetyee.ca/News/2018/03/09/Oklahoma-Toughens-Fracking-Rules/.
[1347] Wethe, "Oklahoma Toughens Oil Fracking Rules after Shale Earthquakes."
[1348] Justin L. Rubinstein, William L. Ellsworth, and Sara L. Dougherty, "The 2013–2016 Induced Earthquakes in Harper and Sumner Counties, Southern Kansas," *Bulletin of the Seismological Society of America* 108, no. 2 (2018): 674–89, https://doi.org/10.1785/0120170209.
[1349] Shelby L. Peterie et al., "Earthquakes in Kansas Induced by Extremely Far-Field Pressure Diffusion," *Geophysical Research Letters* 45, no. 3 (2018): 1395–1401, https://doi.org/10.1002/2017GL076334.
[1350] Chris Dunker, "Spate of Nebraska Earthquakes Might Be Linked to Kansas Tremors, UNL Student Researcher Says," *Lincoln Journal Star*, June 8, 2021, https://journalstar.com/news/local/education/spate-of-nebraska-earthquakes-might-be-linked-to-kansas-tremors/article_b81d0bdc-5b0e-5c98-a155-5f6499356b4d.amp.html?__twitter_impression=true.

shallow subsurface layers and was of short duration and small magnitude. In other, more troubling cases, earthquakes were more powerful and took place in very deep layers, far below the layers being fracked, even when fracking did not directly contact faults in the basement rock. At three of five sites, earthquake activity continued for over a month after fracking activities ceased. These results support a causal role for poroelastic stress, sometimes operating over long distances, in addition to more predictable pore fluid pressure changes, in the generation of earthquakes by fracking.[1351, 1352]

- January 19, 2018 – Some of the largest earthquakes related to fracking have occurred near Fox Creek, Alberta, in Canada. Using publicly available data, researchers studied earthquakes induced both by fracking waste injection and by hydraulic fracturing itself. In both cases, the volume of fluid injected, rather than injection rate or injection pressure, was most strongly correlated with seismic activity. Geologic factors also played a role, with earthquakes more likely if fracking and disposal activities were conducted closer to faulting and areas of stress. Combining injected volume with geologic factors, researchers developed a model that can predict 96 percent of the seismic variability in the region, improving hazard estimations. Calculating a "seismogenic activation potential," particularly if coupled with microseismic monitoring in real time to detect previously unknown faulting, may improve earthquake forecasting.[1353]

- November 24, 2017 – A team of geologists confirmed conclusively that recent earthquakes in Texas' Fort Worth Basin were induced by underground injection of fracking waste that caused deep, critically stressed faults to slip.[1354] The authors of this study employed a classical structural geology analysis that relied on high-resolution seismic reflection imaging, described in an interview with geophysical researcher Maria Magnani as "a little bit like an ultrasound."[1355] Maps of the seismically active faults in the Fort Worth Basin show no evidence of previous motion over the past millions of years and instead have been "sleeping" for approximately the past 300 million years until "awakened" at the start of the 2008 earthquake swarm associated temporally with extensive wastewater injection activities.[1356]

[1351] Maria Kozłowska et al., "Maturity of Nearby Faults Influences Seismic Hazard from Hydraulic Fracturing," *Proceedings of the National Academy of Sciences* 115, no. 8 (2018): E1720–29, https://doi.org/10.1073/pnas.1715284115.
[1352] Kathiann M. Kowalski, "Fracking in Shale Plays Could Trigger Earthquakes in Deeper Faults: Study," *Energy News Network*, February 7, 2018, http://energynews.us/2018/02/07/fracking-in-shale-plays-could-trigger-earthquakes-in-deeper-faults-study/.
[1353] R. Schultz et al., "Hydraulic Fracturing Volume Is Associated with Induced Earthquake Productivity in the Duvernay Play," *Science* 359, no. 6373 (2018): 304–8, https://doi.org/10.1126/science.aao0159.
[1354] Maria Beatrice Magnani et al., "Discriminating between Natural versus Induced Seismicity from Long-Term Deformation History of Intraplate Faults," *Science Advances* 3, no. 11 (November 2017): e1701593, https://doi.org/10.1126/sciadv.1701593.
[1355] Ben Guarino, "Oil and Gas Industry Is Causing Texas Earthquakes, a 'Landmark' Study Suggests," *Washington Post*, November 24, 2017, https://www.washingtonpost.com/news/speaking-of-science/wp/2017/11/24/fracking-and-other-human-activities-are-causing-texas-earthquakes-study-suggests/.
[1356] Anna Kuchment, "Drilling Reawakens Sleeping Faults in Texas, Leads to Earthquakes," *Scientific American*, November 24, 2017, sec. Environment, https://www.scientificamerican.com/article/drilling-reawakens-sleeping-faults-in-texas-leads-to-earthquakes/.

- October 21, 2017 – Extending the findings of two previous studies, an investigation of earthquakes in the Raton Basin along the border of New Mexico and Colorado identified wastewater injection wells as the cause of the quakes and identified a mechanism.[1357] Altogether, the location of the earthquakes, modeled pore pressures, and the direct correlation between cumulative volume of injected waste in nearby wells and the number of quakes show that seismicity in the Raton Basin is likely induced, and that elevated pore pressures deep underground are "well above earthquake-triggering thresholds."[1358]

- September 14, 2017 – An investigation by *Politico* found that the U.S. crude oil storage hub in Cushing, Oklahoma—the world's largest store of oil—was not designed with seismic considerations in mind, nor are there seismic regulations in place for its 250,000-barrel oil tanks, which are under the purview of the Department of Transportation's Pipeline and Hazardous Materials Safety Administration. Central Oklahoma, where Cushing is located, became seismically active about five years ago when "wastewater injection and other fracking-related activities changed the seismic face of Oklahoma in dramatic fashion."[1359] (See also entry below for November 8, 2016.)

- August 11, 2017 – Using multiple lines of evidence, researchers in China determined that a series of high-magnitude earthquakes between 2014 and 2017 in Sichuan Basin was triggered by fracking activities that re-activated pre-existing faults. "The present study shows that short-term injections (continuing over several months) for shale gas hydraulic fracturing are … very likely to induce M_W 4–5 class earthquakes in sites with similar geological and tectonic conditions within the southern Sichuan Basin."[1360]

- May 3, 2017 – Studying two patterns of fracking waste injection in Oklahoma, geologists observed a large, unexpected impact on seismic activity at sites where injection rates drastically changed in recent years, as compared with those whose injection volumes held steady. They demonstrated that, in addition to direct pore pressure effects, deformations due to fluid flows ("poroelastic effects") play an important role in generating earthquake activity. Elevated risks for earthquakes can persist years after fracking waste is injected underground. Their findings also showed that the "magnitude of the initial change in injection rate is particularly important, but the opposite effect occurs in the transition to zero injection" (i.e., shut-in or closing a well). This result implies that "in certain faulting regimes it is theoretically possible to mitigate damaging effects of rapid shut-in by

[1357] J. S. Nakai et al., "A Possible Causative Mechanism of Raton Basin, New Mexico and Colorado Earthquakes Using Recent Seismicity Patterns and Pore Pressure Modeling: Earthquakes in the Raton Basin," *Journal of Geophysical Research: Solid Earth* 122, no. 10 (2017): 8051–65, https://doi.org/10.1002/2017JB014415.
[1358] Jim Scott, "Raton Basin Earthquakes Linked to Oil and Gas Fluid Injections," *CU Boulder Today*, October 24, 2017, https://www.colorado.edu/today/2017/10/24/raton-basin-earthquakes-linked-oil-and-gas-fluid-injections.
[1359] Kathryn Miles, "How Man-Made Earthquakes Could Cripple the U.S. Economy," *Politico Magazine*, September 14, 2017, https://www.politico.com/magazine/story/2017/09/14/earthquakes-oil-us-economy-fracking-215602.
[1360] Xinglin Lei et al., "Fault Reactivation and Earthquakes with Magnitudes of up to Mw4.7 Induced by Shale-Gas Hydraulic Fracturing in Sichuan Basin, China," *Scientific Reports* 7, no. 1 (2017): 7, https://doi.org/10.1038/s41598-017-08557-y.

carefully tapering injection rates."[1361] Geophysicist Andrew Barbour, lead author of the study, said that fluctuating injection rates likely have a "profound effect" on earthquake risk.[1362] These findings suggest that the 2016 Pawnee earthquake, the strongest earthquake ever recorded in Oklahoma, may have been triggered by pulses of underground oil and gas activity years earlier.[1363]

- April 27, 2017 – Recognizing that increased seismicity from both hydraulic fracturing and underground disposal of fracking wastewater poses a hazard to critical infrastructure, such as large dams, a Canadian geologist proposed strategies to keep the likelihood of high-failure consequences under one per ten thousand per year.[1364] The primary strategy is the creation of "no frack" exclusion zones with a 5-kilometer (3.1 mile) radius that would surround vulnerable, critical facilities. In a larger ring beyond the exclusion zone, to approximately 25 kilometers (15.5 miles), monitoring and response protocols would be used.[1365]

- March 1, 2017 – Despite decreases of up to 40 percent in the volume of fracking wastewater injected underground in Oklahoma, researchers from the USGS Earthquake Hazard Program forecasted that seismic hazards would remain significantly elevated there throughout 2017, with the odds of damage from induced earthquakes within the next year "similar to that of natural earthquakes in high-hazard areas of California." About three million people in Oklahoma and southern Kansas now live with continuing increased potential for damaging shaking from induced seismicity."[1366] According to Mark Petersen, chief of the USGS National Seismic Hazard Mapping Project, the hazard risk remains "hundreds of times higher than before man-made activity began."[1367]

- February 17, 2017 – Pennsylvania's Department of Environment Protection (PA DEP) announced that a series of small earthquakes in Lawrence County had been induced by

[1361] Andrew J. Barbour, Jack H. Norbeck, and Justin L. Rubinstein, "The Effects of Varying Injection Rates in Osage County, Oklahoma, on the 2016 M_w 5.8 Pawnee Earthquake," *Seismological Research Letters* 88, no. 4 (2017): 1040–53, https://doi.org/10.1785/0220170003.
[1362] Corey Jones, "USGS Study 'Strongly Suggests' Short-Term Variations in Disposal Volumes Served as Trigger for Pawnee Earthquake," *Tulsa World*, May 7, 2017, https://tulsaworld.com/earthquakes/usgs-study-strongly-suggests-short-term-variations-in-disposal-volumes-served-as-trigger-for-pawnee/article_97de08d5-9327-505d-8b51-adbc716d6c69.html.
[1363] Joe Wertz, "Study Links Pulse of Oil-Field Wastewater to Oklahoma's Strongest Earthquake," *State Impact Oklahoma*, May 4, 2017, https://stateimpact.npr.org/oklahoma/2017/05/04/study-links-pulse-of-oil-field-wastewater-to-oklahomas-strongest-earthquake/.
[1364] Gail M. Atkinson, "Strategies to Prevent Damage to Critical Infrastructure Due to Induced Seismicity," ed. Christoph E. Geiss, *FACETS* 2, no. 1 (2017): 374–94, https://doi.org/10.1139/facets-2017-0013.
[1365] Andrew Nikiforuk, "Earthquake Expert Proposes 'No Frack Zone' around Critical Infrastructure," *The Tyee*, July 24, 2017, https://thetyee.ca/News/2017/07/24/Critical-Infrastructure-No-Frack-Zone/.
[1366] Mark D. Petersen et al., "2017 One-Year Seismic-Hazard Forecast for the Central and Eastern United States from Induced and Natural Earthquakes," *Seismological Research Letters* 88, no. 3 (2017): 772–83, https://doi.org/10.1785/0220170005.
[1367] Adam Wilmoth, "Oklahoma Considered at 'significant Potential' for Damaging Earthquakes," *The Oklahoman*, March 1, 2017, https://oklahoman.com/article/5539785/oklahoma-considered-at-significant-potential-for-damaging-earthquakes/.

fracturing of wells in the Utica Shale.[1368] PA DEP officials held a webinar to discuss the situation and formulate "procedures to reduce seismic risk going forward," but no formal report or regulatory changes have yet been made public.[1369]

- December 20, 2016 – In an attempt to reduce the risk of earthquakes caused directly by fracking, the Oklahoma Corporation Commission's Oil and Gas Conservation Division introduced monitoring and response guidelines that include provisions requiring oil producers to "implement mitigation plans following an earthquake of magnitude 2.5 or more and to suspend operations following a quake of magnitude 3.5 or greater."[1370]

- November 17, 2016 – A study of fault activation found a connection between fracking and earthquake activity in a region of Alberta, Canada that had previously been seismically quiescent. The researchers demonstrated that new earthquake activity in the Fox Creek area was tightly spatially correlated with hydraulic fracturing activities. Their findings further suggested that seismic activity resulted from "stress changes due to the elastic response of the rock mass to hydraulic fracturing," as well as "pore-pressure changes due to fluid diffusion along a permeable fault zone."[1371] In contrast to the central United States, where induced seismic activity is primarily caused by massive underground disposal of fracking waste, these findings pointed to the fracking process itself as the trigger. In an interview with the *New York Times,* co-author David Eaton compared fracking to a series of "small underground explosions" that travel into the rock formation and "rapidly change the stress patterns within." These stress changes can be sufficient to trigger a slip at a critically stressed, previously undetected fault.[1372]

- November 17, 2016 – An investigation by the *Dallas Morning News* chronicled a pattern of corruption and regulatory failings at the Texas Railroad Commission, the state agency charged with overseeing the oil and gas industry, in its disregard of evidence linking fracking waste disposal to earthquakes in North Texas.[1373]

- November 8, 2016 – On November 6, 2016, a magnitude 5.0 earthquake struck Cushing, Oklahoma near the oil hub where 60 million barrels of crude oil were stored. The quake

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[1368] Laura Legere, "DEP Links Lawrence County Earthquakes to Fracking," *Pittsburgh Post-Gazette*, February 16, 2017, https://www.post-gazette.com/business/powersource/2017/02/16/DEP-Pennsylvania-Lawrence-County-earthquakes-appear-linked-to-fracking-Hilcorp-Energy/stories/201702160176.
[1369] Pennsylvania Department of Environmental Protection, "Advisory– Friday– Department of Environmental Protection to Hold Webinar on 2016 Lawrence County Seismic Events," Press Release, February 17, 2017, https://www.ahs.dep.pa.gov/NewsRoomPublic/articleviewer.aspx?id=21145&typeid=1.
[1370] Hampton, "Oklahoma's New Fracking Guidelines Aim to Reduce Quake Risk," *Reuters*, December 20, 2016, https://www.reuters.com/article/us-oklahoma-quake-rules-idUSKBN1492R6.
[1371] Xuewei Bao and David W. Eaton, "Fault Activation by Hydraulic Fracturing in Western Canada," *Science* 354, no. 6318 (2016): 1406–9, https://doi.org/10.1126/science.aag2583.
[1372] Henry Fountain, "In Canada, a Direct Link Between Fracking and Earthquakes," *The New York Times*, November 17, 2016, sec. Science, https://www.nytimes.com/2016/11/18/science/fracking-earthquakes-alberta-canada.html.
[1373] Steve Thompson and Anna Kuchment, "Seismic Denial? Why Texas Won't Admit Fracking Wastewater Is Causing Earthquakes," *Dallas News*, November 17, 2016, http://interactives.dallasnews.com/2016/seismic-denial/#_ga=2.247990020.202656599.1515906987-1750807308.1515724730.

injured one, damaged more than 40 buildings, closed a school, and triggered evacuations. Oil infrastructure was not damaged.[1374] (See also entry above for September 14, 2017.)

- October 7, 2016 – The EPA recommended a moratorium on the underground injection of fracking wastewater in certain earthquake-prone parts of Oklahoma after a 5.8 earthquake struck near Pawnee on September 3, 2016.[1375] The strongest in Oklahoma's history, the Pawnee earthquake was felt by residents in five states and prompted a state of emergency declaration as well as an order from state regulators to shut down 67 wastewater disposal wells in the area.[1376, 1377]

- September 22, 2016 – A study using satellite-based radar imagery found that the earth's surface rose, by 3 millimeters per year, in areas of fracking waste injection. Underground pore pressures for this area exceeded those known to trigger earthquakes. These findings provide proof that the migration of fracking wastewater into faults increased pressures in ways that triggered a 4.8 magnitude earthquake in east Texas in 2012. The researchers emphasized that pore pressure elevation and propagation from fracking wastewater injection may evolve over periods of months to years before affecting critically stressed faults.[1378]

- September 14, 2016 – Researchers from the USGS used a newly deployed seismic monitoring network to document the rupture of a fault plane that set off a magnitude 4.9 earthquake in Milan, Kansas in 2014, immediately following a rapid increase in fracking wastewater injection nearby.[1379]

- June 30, 2016 – Using mathematical equations, researchers can replicate the pattern and intensity of naturally occurring (tectonic) earthquakes in the plots of earthquakes induced by hydraulic fracturing, wastewater disposal, enhanced geothermal stimulation, and subsurface injections for research purposes. In these retrospective examinations, the total number of induced earthquakes follows the volume of fluid injected, while the size of the largest earthquakes induced is not limited by fluid volumes but instead "whatever it is that limits earthquake magnitudes on tectonic faults..." That is, there is nothing intrinsic to the geophysics of induced earthquakes that prevents them from being as large or larger than previously observed naturally occurring earthquakes.[1380]

[1374] Matthew Philips, "Why Oklahoma Can't Turn Off Its Earthquakes," *Bloomberg Businessweek*, November 8, 2016, https://www.bloomberg.com/news/articles/2016-11-08/why-oklahoma-can-t-turn-off-its-earthquakes.
[1375] Mike Soraghan, "EPA Suggests Partial Disposal Moratorium in Okla," *E&E EnergyWire*, October 7, 2016, https://subscriber.politicopro.com/article/eenews/1060043991.
[1376] U.S. Geological Survey, "M 5.8 - 14 Km NW of Pawnee, Oklahoma," September 3, 2016, https://earthquake.usgs.gov/earthquakes/eventpage/us10006jxs/executive#executive.
[1377] Oklahoma Corporation Commission, "Latest Action Regarding Pawnee Area," Media Advisory, September 12, 2016, https://oklahoma.gov/content/dam/ok/en/occ/documents/ajls/news/2016/09-12-16pawnee-advisory.pdf.
[1378] M. Shirzaei et al., "Surface Uplift and Time-Dependent Seismic Hazard Due to Fluid Injection in Eastern Texas," *Science* 353, no. 6306 (2016): 1416–19, https://doi.org/10.1126/science.aag0262.
[1379] George L. Choy et al., "A Rare Moderate-Sized (Mw 4.9) Earthquake in Kansas: Rupture Process of the Milan, Kansas, Earthquake of 12 November 2014 and Its Relationship to Fluid Injection," *Seismological Research Letters* 87, no. 6 (2016): 1433–41, https://doi.org/10.1785/0220160100.
[1380] Nicholas J. van der Elst et al., "Induced Earthquake Magnitudes Are as Large as (Statistically) Expected," *Journal of Geophysical Research: Solid Earth* 121, no. 6 (2016): 4575–90, https://doi.org/10.1002/2016JB012818.

- May 2016 – In a study that has "far-reaching implications for assessment of induced-seismicity hazards," a Canadian team of researchers determined that hydraulic fracturing itself is linked to earthquake swarms in western Canada, in contrast to the central United States where disposal of fracking waste is the cause of most induced seismicity. Furthermore, lowering the volume of injected fluid may not be sufficient to prevent quakes. In the Western Canada Sedimentary Basin, "it appears that the maximum-observed magnitude of events associated with hydraulic fracturing may exceed the prediction of an often-cited relationship between the volume of injected fluid and the maximum expected magnitude…. Rather, we propose that the size of the available fault surface that is in a critical state of stress may control the maximum magnitude…. Our results indicate that the maximum magnitude of induced events for hydraulic fracturing may not be well correlated with net injected fluid volume."[1381]

- April 29, 2016 – Five small earthquakes in one 24-hour period originated in an area in Lawrence County, Pennsylvania near a fracking operation that was drilling into the deep Utica Shale at the time. Quoted in the *Pittsburg Post-Gazette*, researchers noted that it is very difficult for operators to avoid areas with faults because their locations are very often unknown.[1382]

- March 28, 2016 – A summary of the evidence linking drilling and fracking activities to earthquakes appeared in *Scientific American.* Emerging data suggests that pressure changes caused by fracking wastewater injection can migrate for years before encountering a geological fault and altering stresses in ways that allow for slippage. In this way, earthquake risks can spread out over both time and space—traveling for miles beyond the disposal well and persisting for a decade or more as injected fluids travel underground. In spite of increasing scientific clarity about these mechanisms, regulators have been slow to respond.[1383]

- February 1, 2016 – An article in the *Texas Journal of Oil, Gas, and Energy Law* exhaustively reviewed the literature on earthquake activity in areas of six states (Arkansas, Colorado, Kansas, Ohio, Oklahoma, and Texas) where fracking takes place or drilling wastes are disposed underground and concluded that courts should impose strict liability for earthquake damage caused either by fracking itself or by the underground injection of fracking fluids. "Earthquakes sometimes occur when subsurface formations are properly fractured. Likewise, the risk of earthquake damage is not substantially mitigated by the exercise of due care when frack fluids are injected into the ground."[1384]

[1381] Gail M. Atkinson et al., "Hydraulic Fracturing and Seismicity in the Western Canada Sedimentary Basin," *Seismological Research Letters* 87, no. 3 (2016): 631–47, https://doi.org/10.1785/0220150263.
[1382] Laura Legere, "State Studying Link between Fracking, Lawrence County Earthquakes," *Pittsburgh Post-Gazette*, April 29, 2016, https://www.post-gazette.com/business/powersource/2016/04/29/State-studying-link-between-fracking-and-Lawrence-County-earthquakes/stories/201604290099.
[1383] Anna Kuchment, "Drilling for Earthquakes," *Scientific American*, March 28, 2016, https://doi.org/10.1038/scientificamerican0716-46.
[1384] Blake A. Watson, "Fracking and Cracking: Strict Liability for Earthquake Damage Due to Wastewater Injection and Hydraulic Fracturing," SSRN Scholarly Paper (Rochester, NY: Social Science Research Network, February 1, 2016), https://papers.ssrn.com/abstract=2735862.

- January 22, 2016 – An international research team investigated a swarm of earthquakes in California's Central Valley that occurred in 2005. Using hydrogeological modeling, the researchers concluded that the underground injection of wastewater from oil drilling operations had contributed to seismicity via changes in localized pressures along an active fault.[1385]

- January 12, 2016 – As reported by *CBC News*, a Canadian regulatory agency ordered a drilling and fracking operation in northwestern Alberta to shut down after a magnitude 4.8 earthquake struck nearby. The operator was fracking at the time the earthquake happened.[1386]

- November 15, 2015 – A spokesperson for the Oklahoma Corporation Commission, which regulates the oil and gas industry in the state, said that Oklahoma now leads the world in earthquake frequency.[1387]

- October 29, 2015 – The Kansas Corporation Commission extended limits on the injection of wastewater from fracking operations after a drop in the frequency of earthquakes that followed an earlier order to limit such injections.[1388] Between 2013 and October 2015, Kansas recorded more than 200 earthquakes. Before that, the average rate was one earthquake every two years.

- October 23, 2015 – *Bloomberg* explored the national security risks that fracking-induced earthquakes in Oklahoma create for the nation's largest oil storage hub in Cushing, where aboveground tanks hold more than 60 million barrels of crude oil and serve as a way station for oil from North Dakota's Bakken Shale as it heads to Gulf Coast refineries. Earthquake swarms have hit within a few miles of Cushing and may be harbingers of larger quakes in the future. "Now that quakes appear to have migrated closer to Cushing, the issue of what to do about them has morphed from a state issue to one of national security…. Not only is Cushing crucial to the financial side of the oil market, it is integral to the way physical crude flows around the country."[1389]

- September 21, 2015 – An international team of geologists investigated possible causes of the Lusi mudflow, which began suddenly in 2006 when mud began erupting from the

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[1385] T. H. W. Goebel et al., "Wastewater Disposal and Earthquake Swarm Activity at the Southern End of the Central Valley, California," *Geophysical Research Letters* 43, no. 3 (2016): 1092–99, https://doi.org/10.1002/2015GL066948.
[1386] CBC News, "Alberta Fracking Operation Closed Indefinitely after Earthquake," *CBC*, January 12, 2016, https://www.cbc.ca/news/canada/edmonton/fox-creek-fracking-operation-closed-indefinitely-after-earthquake-1.3400605.
[1387] Jessica Miller, "Oklahoma World's No. 1 Earthquake Area," *Enidnews.Com*, November 11, 2015, https://www.enidnews.com/news/local_news/oklahoma-worlds-no-1-earthquake-area/article_69b145b8-c180-5065-8f99-b2a7ec7ce913.html.
[1388] Kansas Corporation Commission, "Kansas Corporation Commission Approves Order Extending Wastewater Injection Limits," News Release, October 29, 2015, https://kcc.ks.gov/news-10-29-15.
[1389] Matthew Philips, "Oklahoma Earthquakes Are a National Security Threat," *Bloomberg*, October 23, 2015, https://www.bloomberg.com/news/articles/2015-10-23/oklahoma-earthquakes-are-a-national-security-threat.

ground in a volcano-like fashion in an urban area of Java in Indonesia. The ongoing disaster has, as of 2015, displaced 39,700 people and cost nearly $3 billion in damages and disaster management. Looking at data on the emissions of subsurface gases before and after the eruption began, the team concluded that the likely cause was nearby gas drilling that forced fluid into the clay layer via the open well. "We therefore conclude that the Lusi eruption was not triggered naturally but was instead the consequence of drilling operations."[1390] In interviews with the *New York Times*, lead author Mark Tinjay said, "We are now 99 percent certain that the drilling hypothesis is valid," while other experts who were not authors of the paper expressed less certainty.[1391]

- July 27, 2015 – During a seven-day period in late July, the state of Oklahoma experienced 40 earthquakes. According to the USGS, three registered above magnitude 4.0, one of which was strong enough to be felt by 1.9 million people, including residents of several surrounding states.[1392] In response, gas and oil operators voluntarily shut down two nearby wastewater injection wells and reduced operations by half at a third well.[1393] According to the Oklahoma Geological Survey, the recent quakes are occurring along a fault line that extends north of Oklahoma City and signal greater potential for a larger earthquake.[1394] Ten days before the voluntary shutdowns, the Oklahoma Corporation Commission, which regulates the oil and gas industry, put 211 wastewater disposal wells under extra review.[1395] The next month, Oklahoma regulators, acknowledging that previous efforts have been unsuccessful in reducing seismic activity, asked operators of 23 injection wells to decrease the amount of wastewater injected by 38 percent and signaled that more sweeping regulatory actions may follow.[1396]

- July 1, 2015 – Two researchers, from the USGS and the Geological Survey of Canada, offered a summary of the history, basic geology, and engineering of fracking fluid injection and induced seismicity. Noting that since 2001 Oklahoma had experienced two earthquakes of very large magnitude (5.0 and 5.3), the authors called for "a detailed understanding of the physical processes involved in inducing large magnitude events and a detailed understanding of the geology and hydrology at the site of the earthquakes." They also noted that many important parameters are either unknown or not easily

[1390] M. R. P. Tingay et al., "Initiation of the Lusi Mudflow Disaster," *Nature Geoscience* 8, no. 7 (2015): 493–94, https://doi.org/10.1038/ngeo2472.
[1391] Rachel Nuwer, "Indonesia's 'Mud Volcano' and Nine Years of Debate About Its Muck," *The New York Times*, September 21, 2015, sec. Science, https://www.nytimes.com/2015/09/22/science/9-years-of-muck-mud-and-debate-in-java.html.
[1392] U.S. Geological Survey, "M 4.5 - 4 Km NNE of Crescent, Oklahoma," July 27, 2015, https://earthquake.usgs.gov/earthquakes/eventpage/us200030gd/executive#impact_pager.
[1393] Oklahoma Corporation Commission, "New Actions Taken in Response to Earthquake Activity in Crescent Area," Media Advisory, July 28, 2015.
[1394] Sean Murphy, "2 Injection Wells Shut down after Oklahoma Quakes," *Santa Cruz Sentinel*, July 28, 2015, https://www.santacruzsentinel.com/2015/07/28/2-injection-wells-shut-down-after-oklahoma-quakes/.
[1395] Oklahoma Corporation Commission, "OCC Announces Next Step in Continuing Response to Earthquake Concerns," Press Release, July 17, 2015.
[1396] Michael Wines, "Oklahoma Acts to Limit Earthquake Risk at Oil and Gas Wells," *The New York Times*, August 5, 2015, sec. U.S., https://www.nytimes.com/2015/08/05/us/oklahoma-acts-to-limit-earthquake-risk-at-oil-and-gas-wells.html.

constrained, making it "difficult to determine the wells that will induce earthquakes and those that will not."[1397]

- June 30, 2015 – The Oklahoma Supreme Court ruled that homeowners who have sustained injuries or property damage that they believe is due to earthquakes caused by oil and gas operations can sue for damages in state trial courts. The number of earthquakes with magnitude 3.0 or higher has skyrocketed in Oklahoma, with 1,100 predicted to occur in 2015. Earlier this year, scientists at the state's geological survey reversed prior views and embraced the conclusion that the majority of the recent earthquakes in central and north-central Oklahoma were "very likely triggered" by underground wastewater disposal. Industry lawyers have complained that liability for such damages will be economically unsustainable. A separate class action lawsuit is planned.[1398]

- June 19, 2015 – By compiling a database of 187,570 injection wells in the central and eastern United States, University of Colorado Boulder and USGS researchers were able to test for associations between fracking waste disposal and earthquakes. Results showed far more injection wells were potentially related to earthquakes than had previously been realized, and active disposal-only wells were more than 1.5 times more likely than active oil extraction wells to be associated with an earthquake. In addition, high-rate injection wells, receiving more than 300,000 barrels of fluid per month, were much more likely than lower-rate wells to be associated with an earthquake, while other factors, including wellhead injection pressure, appeared unrelated to increased earthquake activity. The study called for managing injection rates as "a useful tool to minimize the likelihood of induced earthquakes." The researchers did not address the impact of hydrofracturing activities *per se* as a potential confounding variable.[1399, 1400]

- June 18, 2015 – Close examination of several areas in Oklahoma by Stanford University geophysicists revealed that dramatic increases in recent earthquake activity followed 5- to 10-fold increases in deep-well injection of briny "produced water," the highly salty fluid that rises to the surface from water-bearing oil reserves and requires disposal. The rate of earthquake occurrence, which began to increase in 2009, is now 600 times higher than it was before the onset of widespread fracking in the state. The disposal of this type of waste in Oklahoma mostly occurs via injection into geological formations that appear to be in hydraulic communication with potentially active faults in the crystalline basement. The study proposed that increasing pressure, spreading away from injection wells over time, could eventually trigger slips on critically stressed faults, resulting in earthquake

[1397] Justin L. Rubinstein and Alireza Babaie Mahani, "Myths and Facts on Wastewater Injection, Hydraulic Fracturing, Enhanced Oil Recovery, and Induced Seismicity," *Seismological Research Letters* 86, no. 4 (2015): 1060–67, https://doi.org/10.1785/0220150067.
[1398] Richard A. Oppel Jr., "Oklahoma Court Rules Homeowners Can Sue Oil Companies Over Quakes," *The New York Times*, July 1, 2015, sec. U.S., https://www.nytimes.com/2015/07/01/us/oklahoma-court-rules-homeowners-can-sue-oil-companies-over-quakes.html.
[1399] M. Weingarten et al., "High-Rate Injection Is Associated with the Increase in U.S. Mid-Continent Seismicity," *Science* 348, no. 6241 (2015): 1336–40, https://doi.org/10.1126/science.aab1345.
[1400] Julia Rosen, "Pumped up to Rumble," *Science* 348, no. 6241 (2015): 1299–1299, https://doi.org/10.1126/science.348.6241.1299.

activity. It is likely that, "even if injection from many wells were to stop immediately, seismicity would continue as pressure continues to spread out from past injection."[1401]

- June 12, 2015 – Researchers in France uncovered an unexpected mechanism by which subsurface fluid injections, such as those used in high volume hydrofracturing, can cause earthquakes. They found that injection of pressurized water can cause fault lines to "creep" rather than slip suddenly as occurs during earthquakes. Earthquakes did follow this slow movement but took place in a portion of the fault outside the pressurized zone. This research demonstrated that subsurface injection of fluids under pressure can cause primary gradual slippage of fault planes leading to secondary sudden seismic activity.[1402, 1403]

- June 11, 2015 – As reported by the Vancouver news magazine *The Tyee,* seismic events of magnitude greater than 2.0 (but less than 4.0) in the Fox Creek area were reported in Alberta, Canada since the initiation in February of a novel "traffic light system" for responding to measured seismic activity. The system requires varying responses according to the magnitude of the event, ranging from no action up to ceasing operations and informing the Alberta Energy Regulator for events at magnitudes greater than 4.0. Experts noted that the system does not work well when the largest event in the sequence is the first event. Moreover, once a sequence of earthquakes is initiated, the sequence may continue, sometimes with larger earthquakes, long after potentially causally related drilling or injection activities have ceased.[1404]

- June 1, 2015 – In a data-rich presentation, a team of researchers from St. Louis University, Colorado State University, and USGS concluded that "a fundamental change in the earthquake-triggering process has occurred" in central Oklahoma. Using advanced field monitoring and high-performance software, computer models illustrate active earthquake sequences associated with long fault structures "that might be capable of supporting large earthquakes (M 5 to 6)" and possibly cascades of earthquakes, which could occur near population centers and expensive infrastructure associated with the oil and gas industry, such as a large underground crude-oil storage facility.[1405]

- May 11, 2015 – A series of directives from the Oklahoma Corporation Commission revealed a slowly evolving approach to the regulation of disposal well operations in that state, and the gradual tightening of a "traffic light system" introduced in 2013 to determine whether disposal wells for fracking waste should be permitted, permitted only with special restrictions and requirements, or not permitted, in light of the now-proven

[1401] F. Rall Walsh and Mark D. Zoback, "Oklahoma's Recent Earthquakes and Saltwater Disposal," *Science Advances* 1, no. 5 (2015): e1500195, https://doi.org/10.1126/sciadv.1500195.
[1402] Y. Guglielmi et al., "Seismicity Triggered by Fluid Injection-Induced Aseismic Slip," *Science* 348, no. 6240 (2015): 1224–26, https://doi.org/10.1126/science.aab0476.
[1403] Scott K. Johnson, "Making Tiny Earthquakes to Understand Fracking-Driven Quakes," *Ars Technica*, June 11, 2015, https://arstechnica.com/science/2015/06/making-tiny-earthquakes-to-understand-fracking-driven-quakes/.
[1404] Andrew Nikiforuk, "More Industry Linked Earthquakes Recorded in Alberta," *The Tyee*, June 11, 2015, http://thetyee.ca/News/2015/06/11/More-Fracking-Earthquakes/.
[1405] D. E. McNamara et al., "Efforts to Monitor and Characterize the Recent Increasing Seismicity in Central Oklahoma," *The Leading Edge* 34, no. 6 (2015): 628–39, https://doi.org/10.1190/tle34060628.1.

connection between the injection of liquid waste and the soaring frequency of earthquakes in Oklahoma. Since 2013, earthquake activity in Oklahoma has continued to increase in rate and intensity.[1406, 1407]

- April 23, 2015 – In a first-of-its-kind approach, the USGS is updating its National Seismic Hazard Model to address the rapidly increasing, highly variable, and difficult-to-predict hazards of induced earthquakes.[1408] This initial report identified 17 areas within eight states (Alabama, Arkansas, Colorado, Kansas, New Mexico, Ohio, Oklahoma, and Texas) with increased rates of induced seismicity, including many areas experiencing earthquakes of large magnitude.[1409] Two days before the release of this report, Oklahoma's state government acknowledged for the first time that wastewater disposal related to oil and gas drilling is "very likely" to blame for the huge surge of earthquakes in many areas of Oklahoma, the *New York Times* reported.[1410] Several states have developed protocols to shut down existing wells and halt drilling of new disposal wells following an upsurge in earthquake activity.

- April 21, 2015 – Analyzing the unusual increase of seismicity in north Texas since 2008, researchers from Southern Methodist University, the USGS, and University of Texas at Austin concluded that observed earthquake swarms were associated both with extraction (of gas and brine formation waters) and injection (of fracking wastewater), via significant stress changes at earthquake depths. The research team noted that baseline pressure monitoring data, though easy to obtain and routinely collected by industry at well sites, were currently "neither required nor typically available for analysis." Greater transparency and cooperation in regional seismic monitoring is needed to generate more comprehensive data sets that are necessary for robust earthquake hazard analysis, they asserted.[1411, 1412]

- April 21, 2015 – In a statement reporting on an increase in earthquakes in Oklahoma of greater than magnitude 3.0 from less than two per year historically to over two per day in 2015, the Oklahoma Geological Society acknowledged that that the primary, suspected source of "triggered seismicity" is the injection and disposal of produced water associated with oil and gas production.[1413]

[1406] Oklahoma Corporation Commission, "OCC Continuing Response to Triggered Seismicity Concerns," May 11, 2015, https://oklahoma.gov/occ/news/news-releases/news-archives/2015-news-releases.html.
[1407] Oklahoma Corporation Commission.
[1408] Mark D. Petersen et al., "Incorporating Induced Seismicity in the 2014 United States National Seismic Hazard Model—Results of 2014 Workshop and Sensitivity Studies," Open-File Report, Open-File Report, 2015.
[1409] U.S. Geological Survey, "New Insight on Ground Shaking from Man-Made Earthquakes," Open-File Report, Open-File Report (USGS Newisroom, April 23, 2015).
[1410] Richard Pérez-Peña, "U.S. Maps Pinpoint Earthquakes Linked to Quest for Oil and Gas," *The New York Times*, April 23, 2015, sec. U.S., https://www.nytimes.com/2015/04/24/us/us-maps-areas-of-increased-earthquakes-from-human-activity.html.
[1411] Matthew J. Hornbach et al., "Causal Factors for Seismicity near Azle, Texas," *Nature Communications* 6, no. 1 (2015): 6728, https://doi.org/10.1038/ncomms7728.
[1412] Marice Richter, "Small North Texas Quakes Likely Linked to Oil, Gas Operations - Study," *Reuters*, April 21, 2015, sec. Commodities, https://www.reuters.com/article/us-usa-texas-earthquake-idUSKBN0NC2DY20150421.
[1413] Richard D. Andrews and Austin Holland, "Statement on Oklahoma Seismicity" (Oklahoma Geological Survey, April 21, 2015).

- March 30, 2015 – *Bloomberg Business* reported that Oklahoma state seismologists had received pressure from oil industry representatives to downplay the evidence linking fracking wastewater disposal to the soaring frequency of earthquakes in the state.[1414]

- March 6, 2015 – A careful and detailed analysis of historical data coupled with onsite, real-time measurements of seismic activity in central Oklahoma via rapidly deployed seismic sensors revealed that reactivated ancient faults responsible for thousands of earthquakes in Oklahoma are capable of causing larger seismic events. Current hazard maps did not include induced seismicity and therefore underestimate earthquake hazard, the USGS reported. Until new hazard maps become available, providing information about the type, length, and location of these reactivated faults could provide guidance to the oil and gas industry and help inform public policy decisions.[1415] In addition, noted lead author Dan McNamara, such information can "aid in adapting building codes to ensure that structures can withstand more damaging earthquakes.[1416]

- February 20, 2015 – Scientists with the USGS reported in *Science* about grappling with an unexpected increase in injection-related seismic activity across the middle of North America. In 2014, the number of measured earthquakes with magnitude of 3 or greater in Oklahoma exceeded that in California, and observations increasingly suggested that the effects of fluid injection were not confined to the target formation but instead were communicated, sometimes to greater depths, along pre-existing faults. Making hazard modeling more difficult, "most of these faults are only detected when they are imaged by well-located induced earthquakes." Consequently, predicting and controlling such seismic activity may not be possible, leading to a recommendation that injection projects should be sited away from population centers.[1417]

- February 5, 2015 – Citing an association between increased water use and fracking-induced seismic activity, a research scientist at the Geological Survey of Canada offered the quantity of water injected underground as his hypothesis for an observed increase in the frequency and magnitude of earthquake activity in areas near fracking wells. Although the Council of Canadian Academies in 2014 called for more monitoring and data collection, there are only ten monitoring stations in British Columbia, overseeing the

[1414] Ben Elgin and Matthew Philips, "Big Oil Pressured Scientists Over Fracking Wastewater's Link to Quakes," *Bloomberg*, March 30, 2015, https://www.bloomberg.com/news/articles/2015-03-30/big-oil-pressured-scientists-over-fracking-wastewater-s-link-to-quakes.
[1415] D. E. McNamara et al., "Earthquake Hypocenters and Focal Mechanisms in Central Oklahoma Reveal a Complex System of Reactivated Subsurface Strike-Slip Faulting: Earthquake Source Parameters in Oklahoma," *Geophysical Research Letters* 42, no. 8 (2015): 2742–49, https://doi.org/10.1002/2014GL062730.
[1416] H. Koontz, "Reawakened Oklahoma Faults Could Produce Larger Future Events," Press Release (U.S. Geological Survey, March 6, 2015), https://www.usgs.gov/news/reawakened-oklahoma-faults-could-produce-larger-future-events#:~:text=Reawakened%20Oklahoma%20Faults%20Could%20Produce%20Larger%20Future%20Events,Survey%20research%20published%20today%20in%20Geophysical%20Research%20Letters.
[1417] A. McGarr et al., "Coping with Earthquakes Induced by Fluid Injection," *Science* 347, no. 6224 (2015): 830–31, https://doi.org/10.1126/science.aaa0494.

operations of thousands of fracking wells, reported the *Vancouver Observer*.[1418]

- January 29, 2015 – The industry-funded Alberta Energy Regulator confirmed that the location of an earthquake of magnitude 4.4 near Fox Creek, Alberta, was "consistent with being induced by hydraulic fracturing operations," making it the largest felt earthquake yet believed to be related to fracking. Despite claims from industry that tremors related to deep-level fracking could never reach magnitudes that would allow them to be felt on the surface, Gail Atkinson, who holds the Canada Research Chair in Induced Seismicity Hazards at Western University in Ontario, noted, "With fracking, the magnitudes have been increasing every year."[1419]

- January 6, 2015 – Using a specialized program, Miami University researchers analyzed data from multiple seismic stations and determined that a cluster of 77 earthquakes in Poland Township, Ohio, which occurred over the course of a little more than a week, was related temporally and spatially to active hydraulic fracturing operations. When the fracturing operations were shut down, the rate of earthquake activity declined to only 6 events in the next 12 hours and only a single event over approximately the next two months. Among this cluster of seismic activity, an earthquake of magnitude 3.0 ranks as one of the largest earthquakes in the United States to be induced by hydraulic fracturing. The mechanism for these earthquakes appears to be induction of slip along a pre-existing fault or fracture zone. Because "no known fault or historical seismicity had been [previously] identified in the area," regulations prohibiting fracturing within three miles of a known fault would not have been protective.[1420, 1421]

- December 18, 2014 – In Canada, an investigation by the British Columbia Oil and Gas Commission found that induced seismicity in the Horn River Basin could be attributed both to wastewater disposal and to hydraulic fracturing operations. The Commission recommended mitigation of induced seismicity from wastewater disposal by "reducing injection rates, limiting the increase in [subsurface] reservoir pressure, and locating distal from faults," among other mitigation techniques.[1422, 1423]

- October 23, 2014 – Researchers from USGS and the Global Seismological Services in Golden, Colorado, linked a 2011 magnitude 5.3 earthquake in Colorado, which damaged

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[1418] Derek Leahy, "Fracking-Induced Earthquake Puts B.C. Gas Bonanza on Shaky Ground," *Vancouver Observer*, February 5, 2015, https://web.archive.org/web/20150207085334/http://www.vancouverobserver.com/news/fracking-induced-earthquake-puts-bc-gas-bonanza-shaky-ground.
[1419] Andrew Nikiforuk, "Did Alberta Just Break a Fracking Earthquake World Record?," *The Tyee*, January 29, 2015, http://thetyee.ca/News/2015/01/29/Alberta-Fracking-Earthquake/.
[1420] Robert J. Skoumal, Michael R. Brudzinski, and Brian S. Currie, "Earthquakes Induced by Hydraulic Fracturing in Poland Township, Ohio," *Bulletin of the Seismological Society of America* 105, no. 1 (2015): 189–97, https://doi.org/10.1785/0120140168.
[1421] Michael Wines, "New Research Links Scores of Earthquakes to Fracking Wells Near a Fault in Ohio," *The New York Times*, January 8, 2015, sec. U.S., https://www.nytimes.com/2015/01/08/us/new-research-links-scores-of-earthquakes-to-fracking-wells-near-a-fault-in-ohio.html.
[1422] BC Oil and Gas Commission, "Investigation of Observed Seismicity in the Montney Trend," Technical Report, 2014, https://www.bcogc.ca/files/reports/Technical-Reports/investigation-observed-seismicity-montney-trend.pdf.
[1423] Andrew Nikiforuk, "Fracking Industry Shakes Up Northern BC with 231 Tremors," *The Tyee*, January 10, 2015, https://doi.org/10/Fracking_Industry_Shakes_Up_Northern_BC/.

the foundations of several homes, to underground disposal of fracking wastewater. The study determined that the earthquake ruptured an 8-10 kilometer-long segment of normal faults—an unexpectedly long length for a magnitude 5.3 earthquake—suggesting that wastewater disposal may have triggered a low stress drop.[1424] Lead author Bill Barnhart, a USGS geophysicist, told *Reuters*, "We saw a big increase in seismicity starting in 2001, including magnitude 5 earthquakes, in many locations in the basin, and that coincided with a surge in gas production and injection of wastewater."[1425]

- September 23, 2014 – Youngstown State University geologist Ray Beiersdorfer described increased seismic activity in Youngstown, Ohio in an essay that explores how fracking and fracking-related processes are causing "earthquake epidemics" across the United States.[1426]

- September 15, 2014 – Researchers at the National Energy Technology Laboratory teamed up with researchers from industry and academia to publish data and analysis from a closely watched project that involved field monitoring of the induced fracturing of six horizontal Marcellus Shale gas wells in Greene County, Pennsylvania. Touted in earlier media reports as demonstrating that, during short-term follow-up, fracking chemicals injected into these six wells did not spread to overlying aquifers[1427], the study's most notable finding is striking documentation of fractures from three of the six wells extending vertically to reach above an overlying rock layer previously thought to create an impenetrable "frac barrier" (that is, an upper barrier to fracture growth). In one case, a fracture extended vertically 1,900 feet, a surprisingly far distance. No pre-existing fault had been detected at this location, suggesting that small "pre-existing fractures or small-offset (sub-seismic) faults may have focused the energy of hydraulic fractures on certain areas…." Perhaps because of the extremely small sample size and a design focused primarily on monitoring for potential gas and fluid migration, the study's analysis includes no discussion of the seismic relevance of extremely long, vertical induced fractures.[1428]

- September 15, 2014 – Scientists from USGS ascribed causality to wastewater injection wells from coal-bed methane production for increases in seismic activity in New Mexico and Colorado and, in particular, for an earthquake that measured magnitude 5.3 in

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[1424] W. D. Barnhart et al., "Seismological and Geodetic Constraints on the 2011 M_w 5.3 Trinidad, Colorado Earthquake and Induced Deformation in the Raton Basin: 2011 Trinidad, CO Earthquake," *Journal of Geophysical Research: Solid Earth* 119, no. 10 (2014): 7923–33, https://doi.org/10.1002/2014JB011227.
[1425] Laura Zuckerman, "Gas Wastewater Likely Triggered 2011 Quake in Colorado: USGS," *Reuters*, October 30, 2014, sec. Environment, https://www.reuters.com/article/us-usa-earthquake-colorado-idUSKBN0II2NP20141029.
[1426] Ray Beiersdorfer, "View: On Fracking, Earthquakes and Indian Point," *The Journal News*, accessed September 19, 2021, https://www.lohud.com/story/opinion/contributors/2014/09/23/view-geologist-warns-fracking-ties-earthquakes/16100755/.
[1427] Kevin Begos, "DOE Study: Fracking Chemicals Didn't Taint Water," *USA Today*, July 19, 2013, https://www.usatoday.com/story/money/business/2013/07/19/doe-study-fracking-didnt-taint/2567721/.
[1428] R. Hammack et al., "An Evaluation of Fracture Growth and Gas/Fluid Migration as Horizontal Marcellus Shale Gas Wells Are Hydraulically Fractured in Greene County, Pennsylvania," Technological Report (U.S. Department of Energy, 2014).

Colorado in 2011—the second largest earthquake to date for which there is clear evidence that the earthquake sequence was induced by fluid injection.[1429]

- September 6, 2014 – The Ohio Department of Natural Resources suspended operations at two deep-injection wells for fracking wastewater near Warren in northeastern Ohio after discovering evidence that the operation possibly caused a magnitude 2.1 earthquake. The injection well operator, American Water Management Services, had recently received permission to increase pressures at the site of the wells. In 2012, Governor John Kasich had halted disposal of fracking wastewater surrounding a well site in the same region after a series of earthquakes were tied to a deep-injection well. The company that ran that well has disputed the link. The state placed seismic-monitoring devices in the Warren area under protocols adopted after the series of earthquakes in nearby Youngstown.[1430]

- September 1, 2014 – Explaining the need for increased seismic monitoring, Andrew Beaton, Director of the Alberta Geological Survey, stated that over a long period of time, stresses increase in and around an injection wellbore. Seismic movement can be caused if the rate of injection is too fast or if there is a geological feature, such as a fault or fracture in nearby areas. Although Albertans in rural areas have been reporting for years that they can feel tremors under their feet near oil and gas activity, especially around areas of fracking, the Alberta Energy Regulator noted that deep well injections have been shown to create more of an earthquake hazard than hydraulic fracturing. Alberta experienced 819 earthquakes between 1918 and 2009. In comparison, Saskatchewan recorded 13 in the same time period and British Columbia recorded more than 1,200 earthquakes in 2007 alone. There are currently 24 seismic monitors in Alberta, which are tied into other networks, such as those belonging to Environment Canada, University of Calgary, and University of Alberta.[1431]

- August 26, 2014 – In a first-of-its-kind lawsuit, a resident of Prague, Oklahoma, sued two energy companies after rocks fell from her chimney and injured her leg during an earthquake of greater than magnitude 5. The lawsuit claims that underground injection of fracking wastewater conducted by New Dominion LLC and Spess Oil Company has caused shifts in fault lines that have resulted in earthquakes.[1432]

- July 31, 2014 – William Ellsworth, a research geophysicist at the USGS Earthquake Science Center, reported that USGS is developing a hazard model that takes induced earthquakes into account. In addition, residents of Oklahoma, where a sharp spike in

[1429] Justin L. Rubinstein et al., "The 2001-Present Induced Earthquake Sequence in the Raton Basin of Northern New Mexico and Southern Colorado," *Bulletin of the Seismological Society of America*, 2014, https://doi.org/10.1785/0120140009.
[1430] J. C. Smyth, "Ohio Halts Injections at Two Wells for Fracking Wastewater after Quake," *The Columbus Dispatch*, September 6, 2014, https://www.dispatch.com/article/20140906/NEWS/309069872.
[1431] Rachel Maclean, "Earthquake Hazard Linked with Deep Well Injection in Alberta," *CBC News*, September 1, 2014, https://www.cbc.ca/news/canada/calgary/earthquake-hazard-linked-with-deep-well-injection-in-alberta-1.2751963.
[1432] Leslie Rangel, "Prague Resident Files Lawsuit against Two Okla. Energy Companies Following Earthquake Injury," *KFOR.Com Oklahoma City*, August 26, 2014, https://kfor.com/news/prague-resident-files-lawsuit-against-two-okla-energy-companies-following-earthquake-injury/.

earthquake activity has been noted over the past decade, are showing an increased interest in obtaining earthquake insurance.[1433]

- July 3, 2014 – Using data from the Oklahoma Corporation Commission, a team of researchers led by Cornell University geophysicist Katie Keranen found that a steep rise in earthquakes in Oklahoma can be explained by fluid migration from wastewater disposal wells. Moreover, injected fluids in high volume wells triggered earthquakes over 30 kilometers (over 18 miles) away. All of the wells analyzed were operated in compliance with existing regulations. Similar mechanisms may function in other states with high volumes of underground injection of wastewater from unconventional oil and gas production.[1434] Reporting on the study and the increase in earthquakes across the United States and the link to fracking and wastewater disposal, the *Associated Press* noted that some states, including Ohio, Oklahoma, and California, have introduced new rules compelling drillers to measure the volumes and pressures of their injection wells as well as to monitor seismicity during fracking operations.[1435]

- July 1, 2014 – Seismologists linked the emergence of a giant sinkhole that formed in August 2012 near Bayou Corne in southeast Louisiana to tremors (earthquakes) caused by high-pressure pulses of either natural gas or water charged with natural gas. The surges of natural gas that caused the explosive tremors (earthquakes) may have weakened an adjacent salt cavern and caused its collapse. Alternatively, part of the salt cavern may have collapsed, causing a nearby gas pocket to give off surges of gas, later followed by the complete collapse of the salt cavern. These findings help illuminate the role of pressurized fluids in triggering seismic events.[1436]

- June 24, 2014 – Following two earthquakes within a one-month period, the Colorado Oil and Gas Conservation Commission directed High Sierra Water Services to stop disposing wastewater into one of its Weld County injection wells. Monitoring by a team of seismologists from the University of Colorado had picked up evidence of continuing low-level seismic activity near the injection site, including a magnitude 2.6 event less than a month following a magnitude 3.4 earthquake that shook the Greeley area on May 31, 2014.[1437]

[1433] Joe Eaton, "Oklahoma Grapples With Earthquake Spike—And Evidence of Industry's Role," *National Geographic*, August 2, 2014, sec. Science, https://www.nationalgeographic.com/science/article/140731-oklahoma-earthquake-spike-wastewater-injection.
[1434] K. M. Keranen et al., "Sharp Increase in Central Oklahoma Seismicity since 2008 Induced by Massive Wastewater Injection," *Science* 345, no. 6195 (2014): 448–51, https://doi.org/10.1126/science.1255802.
[1435] Emily Schmall and Justin Jouzapavicius, "Answers on Link between Injection Wells and Quakes," *AP NEWS*, July 14, 2014, sec. Hydraulic fracturing, https://apnews.com/article/hydraulic-fracturing-oklahoma-earthquakes-wastewater-fort-worth-fc32049fda854eaa9982818d149fec26.
[1436] A. Nayak and D. S. Dreger, "Moment Tensor Inversion of Seismic Events Associated with the Sinkhole at Napoleonville Salt Dome, Louisiana," *Bulletin of the Seismological Society of America* 104, no. 4 (2014): 1763–76, https://doi.org/10.1785/0120130260.f
[1437] John Tomasic, "Colorado Drilling Regulators Halt Injection-Well Activity in Reaction to Greeley Quake," *The Colorado Independent*, June 24, 2014, https://www.coloradoindependent.com/2014/06/24/colorado-drilling-regulators-halt-injection-well-activity-in-reaction-to-greeley-quake/.

- May 6, 2014 – The USGS and Oklahoma Geological Survey (OGS) jointly issued an official earthquake warning for Oklahoma, pointing out that the number of earthquakes in the state has risen 50 percent since just October—when the two agencies had issued a prior warning. The advisory stated that this dramatic increase in the frequency of small earthquakes "significantly increases the chance for a damaging quake in central Oklahoma." Injection wells used for the disposal of liquid fracking waste have been implicated as the presumptive cause of the earthquake swarm. According to the OGS, about 80 percent of the state of Oklahoma is closer than ten miles from an injection well.[1438] Since the joint earthquake advisory was released in May, the number of earthquakes in Oklahoma has continued to rise. During the first four months of 2014, Oklahoma had experienced 109 earthquakes of magnitude 3 or higher on the Richter scale. By mid-June, the number of earthquakes had topped 200, exceeding the frequency of earthquakes in California.[1439]

- May 2, 2014 – At the annual meeting of the Seismological Society of America, leading geologists warned that the risks and impacts of earthquakes from fracking and injection wells are even more significant than previously thought, pointing out that such earthquakes could occur tens of miles away from wells themselves, including quakes greater than magnitude 5.0. Justin Rubinstein, a research geophysicist at the USGS said, "This demonstrates there is a significant hazard. We need to address ongoing seismicity."[1440] Seismologist Gail Atkinson reported, "We don't know how to evaluate the likelihood that a [fracking or wastewater] operation will be a seismic source in advance."[1441]

- April 11, 2014 – State geologists reported a link between fracking and a spate of earthquakes in Ohio, prompting the Ohio Department of Natural Resources to place a moratorium on drilling in certain areas and to require greater seismic monitoring.[1442]

- April 3, 2014 – Researchers linked earthquakes in Mexico to fracking in the Eagle Ford Shale, which extends beneath both southern Texas and northern Mexico. They also noted a statistical correlation between seismic activity and fracking, particularly in the border

[1438] U.S. Geological Survey, "Record Number of Oklahoma Tremors Raises Possibility of Damaging Earthquakes," Press Release, May 6, 2014, https://www.usgs.gov/news/record-number-oklahoma-tremors-raises-possibility-damaging-earthquakes.
[1439] Hailey Branson-Potts, "Oklahoma Coming to Terms with Unprecedented Surge in Earthquakes," *Los Angeles Times*, June 18, 2014, sec. World & Nation, https://www.latimes.com/nation/la-na-oklahoma-earthquakes-20140618-story.html.
[1440] Bryan Walsh, "The Seismic Link Between Fracking and Earthquakes," *Time*, May 1, 2014, https://time.com/84225/fracking-and-earthquake-link/.
[1441] Patrick J. Kiger, "Scientists Warn of Quake Risk From Fracking Operations," *National Geographic*, May 2, 2014, sec. Science, https://www.nationalgeographic.com/science/article/140502-scientists-warn-of-quake-risk-from-fracking-operations.
[1442] Paresh Dave, "Ohio Finds Link between Fracking and Sudden Burst of Earthquakes," *Los Angeles Times*, April 12, 2014, sec. World & Nation, https://www.latimes.com/nation/nationnow/la-na-nn-ohio-finds-link-fracking-earthquakes-20140411-story.html.

state of Nuevo Leon, which registered at least 31 quakes between magnitude 3.1 and 4.3.[1443]

- April 2014 – Researchers from the University of Alberta and the Alberta Geological Survey published a study in the *Journal of Geophysical Research* that found wastewater injection in Alberta is highly correlated with spikes of seismic activity between October 2006 and March 2012.[1444] On November 13, 2014, *CBC News* reported on a more recent increase in earthquakes, which may also be linked to injection wells.[1445]

- March 7, 2014 – USGS researchers published a study confirming that Oklahoma's damaging magnitude 5.7 earthquake in 2011 was caused by fracking wastewater injection.[1446] One of the authors of the study, seismologist Elizabeth Cochran, noted, "Even if wastewater injection only directly affects a low-hazard fault, those smaller events could trigger an event on a larger fault nearby."[1447]

- January 30, 2014 – A USGS research team linked the rise in earthquakes in Colorado to fracking wastewater injection wells and announced that a study will be published in six to nine months.[1448]

- December 12, 2013 – The *New York Times* detailed the growing link between fracking wastewater injection wells and earthquakes, as well as between fracking itself and earthquakes, with a focus on Oklahoma and a recent magnitude 4.5 earthquake there. As the *New York Times* noted, "Oklahoma has never been known as earthquake country, with a yearly average of about 50 tremors, almost all of them minor. But in the past three years, the state has had thousands of quakes. This year has been the most active, with more than 2,600 so far, including 87 last week…. State officials say they are concerned, and residents accustomed to tornadoes and hail are now talking about buying earthquake insurance."[1449]

[1443] Emilio Godoy, "Fracking, Seismic Activity Grow Hand in Hand in Mexico," *Inter Press Service*, April 3, 2014, sec. Development & Aid, http://www.ipsnews.net/2014/04/fracking-seismic-activity-grow-hand-hand-mexico/.
[1444] Ryan Schultz, Virginia Stern, and Yu Jeffrey Gu, "An Investigation of Seismicity Clustered near the Cordel Field, West Central Alberta, and Its Relation to a Nearby Disposal Well," *Journal of Geophysical Research: Solid Earth* 119, no. 4 (2014): 3410–23, https://doi.org/10.1002/2013JB010836.
[1445] Kim Trynacity, "'Industrial Activities' Could Trigger Earthquakes in Alberta, Researcher Says," *CBC News*, November 10, 2014, https://www.cbc.ca/news/canada/edmonton/fracking-linked-to-alberta-earthquakes-study-indicates-1.2829484.
[1446] Danielle F. Sumy et al., "Observations of Static Coulomb Stress Triggering of the November 2011 *M* 5.7 Oklahoma Earthquake Sequence," *Journal of Geophysical Research: Solid Earth* 119, no. 3 (2014): 1904–23, https://doi.org/10.1002/2013JB010612.
[1447] Becky Oskin, "Wastewater Injection Triggered Oklahoma's Earthquake Cascade," *Live Science*, March 7, 2014, https://www.livescience.com/43953-wastewater-injection-earthquake-triggering.html.
[1448] Lesley McClurg, "Earthquakes in Southern Colorado Linked to Oil and Gas Production," *Colorado Public Radio*, January 30, 2014, https://www.cpr.org/show-segment/earthquakes-in-southern-colorado-linked-to-oil-and-gas-production/.
[1449] Henry Fountain, "Experts Eye Oil and Gas Industry as Quakes Shake Oklahoma," *The New York Times*, December 12, 2013, sec. Science, https://www.nytimes.com/2013/12/13/science/earth/as-quakes-shake-oklahoma-scientists-eye-oil-and-gas-industry.html.

- November 19, 2013 – *Reuters* reported that a series of Oklahoma earthquakes in September of 2013 damaged several homes, and that more scientists in a number of states are concerned about earthquakes related to oil and gas development. Seismologist Austin Holland with the University of Oklahoma said, "This is a dramatic new rate of seismicity."[1450]

- July 19, 2013 – A study from the Lamont-Doherty Earth Observatory linked 109 earthquakes in Youngstown, Ohio to fracking wastewater disposal.[1451, 1452]

- July 11, 2013 – A study in *Science* by Columbia University's Lamont-Doherty Earth Observatory showed that deep-well injection of fracking waste can stress geological faults in ways that make them vulnerable to slipping. The research shows that distant natural earthquakes triggered swarms of smaller earthquakes on critically stressed faults. The researchers wrote, "The fluids [in wastewater injection wells] are driving the faults to their tipping point…. Areas with suspected anthropogenic earthquakes are more susceptible to earthquake-triggering from natural transient stresses generated by the seismic waves of large remote earthquakes."[1453]

- April 2013 – A group of British researchers stated that hydraulic fracturing itself was the likely cause of at least three earthquakes powerful enough to be felt by human beings at the surface. The researchers proposed that increases in the fluid pressure in fault zones were the causal mechanism for these three known instances of "felt seismicity" in the United States, Canada, and the United Kingdom. The largest of these earthquakes was a magnitude 3.8 in the Horn River Basin, Canada.[1454]

- March 26, 2013 – Scientists from the University of Oklahoma, Columbia University and USGS linked a 2011 swarm of earthquakes in Oklahoma to fracking waste disposal in that state.[1455] This included a magnitude 5.7 earthquake—possibly the largest ever triggered by wastewater injection—that injured two people, destroyed 14 homes, and was felt across 17 states.[1456] The research team concluded in a paper in the journal *Geology*

[1450] Carey Gillam, "In Oklahoma, Water, Fracking - and a Swarm of Quakes," *Reuters*, November 19, 2013, sec. Environment, https://www.reuters.com/article/us-usa-earthquakes-fracking-oklahoma-idUSBRE9AI12W20131119.
[1451] Won-Young Kim, "Induced Seismicity Associated with Fluid Injection into a Deep Well in Youngstown, Ohio," *Journal of Geophysical Research: Solid Earth* 118, no. 7 (2013): 3506–18, https://doi.org/10.1002/jgrb.50247.
[1452] B. Chameides, "Fracking Waste Wells Linked to Ohio Earthquakes," *Scientific American*, September 5, 2013, https://www.scientificamerican.com/article/fracking-waste-wells-linked-to-ohio-earthquakes/.
[1453] Sharon Begley, "Study Raises New Concern about Earthquakes and Fracking Fluids," *Reuters*, July 11, 2013, sec. Environment, https://www.reuters.com/article/us-science-fracking-earthquakes-idUSBRE96A0TZ20130711.
[1454] Richard Davies et al., "Induced Seismicity and Hydraulic Fracturing for the Recovery of Hydrocarbons," *Marine and Petroleum Geology* 45 (2013): 171–85, https://doi.org/10.1016/j.marpetgeo.2013.03.016.
[1455] Mark Drajem and Jim Efstathiou Jr., "Oklahoma Quake Tied to Drilling Wastes Adds Pressure for Rules," *Bloomberg*, March 27, 2013, https://www.bloomberg.com/news/articles/2013-03-26/oklahoma-earthquake-in-2011-tied-to-wastewater-wells-in-fracking.
[1456] Michael Behar, "Fracking's Latest Scandal? Earthquake Swarms," *Mother Jones*, April 2013, https://www.motherjones.com/environment/2013/03/does-fracking-cause-earthquakes-wastewater-dewatering/.

that their data called into question the previously predicted maximum size of injection-induced earthquakes.[1457, 1458]

- December 14, 2012 – At a 2012 American Geophysical Union meeting, scientists presented data and concluded that some U.S. states, including Oklahoma, Texas and Colorado, have experienced a significant rise in seismic activity coinciding with a boom in gas drilling, fracking and wastewater disposal. Scientists further found that Oklahoma has seen a significant increase in earthquakes linked to wastewater injection, that a 5.3 earthquake in New Mexico was linked to wastewater injection, and that earthquakes were increasingly common within two miles of injection wells in the Barnett Shale region of Texas. Art McGarr, a researcher at the USGS Earthquake Science Center, concluded that, "The future probably holds a lot more in induced earthquakes as the gas boom expands."[1459]

- November 30, 2012, January 11, 2012, December 22, 2009 – In three different sets of comments on proposed fracking guidelines and regulations, citing scientific reports linking oil and gas infrastructure to seismic activity, the New York City Department of Environmental Protection (NYC DEP) raised serious concerns about the impacts of potential seismic activity from fracking-related activities on New York City's water supply infrastructure. Between 2009 and 2012, the NYC DEP consistently raised concerns that seismic activity surrounding New York City's aquifers and watershed infrastructure could threaten the city's drinking water supply by triggering microseismic events and small induced earthquakes that, in turn, could threaten the integrity of the aging, 100-mile-long aqueducts that carry drinking water from the Catskill Mountains into the New York City metropolitan area. The agency expressed specific concerns about the ability of hydraulic fracturing fluids to migrate underground and to intercept and reactivate faults miles away.[1460, 1461, 1462]

- September 6, 2012 – The British Columbia Oil and Gas Commission determined that fracking itself causes earthquakes, pointing to the results of a probe into 38 seismic

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[1457] Katie M. Keranen et al., "Potentially Induced Earthquakes in Oklahoma, USA: Links between Wastewater Injection and the 2011 Mw 5.7 Earthquake Sequence," *Geology* 41, no. 6 (2013): 699–702, https://doi.org/10.1130/G34045.1.
[1458] Francie Diep, "Study: Wastewater Injection Caused Oklahoma's Largest-Ever Earthquake," *Popular Science*, March 18, 2019, https://www.popsci.com/science/article/2013-03/largest-earthquake-ever-linked-lightly-regulated-wastewater-wells/.
[1459] Jessica Leber, "Studies Link Earthquakes to Wastewater from Fracking," *MIT Technology Review*, December 14, 2012, https://www.technologyreview.com/2012/12/14/181149/studies-link-earthquakes-to-wastewater-from-fracking/.
[1460] New York City Department of Environmental Protection, "New York City Comments on: Draft Supplemental Generic Environmental Impact Statement (dSGEIS) on the Oil, Gas and Solution Mining Regulatory Program – Well Permit Issuance for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs," December 22, 2009, https://www.state.nj.us/drbc/library/documents/dockets/stone-energy/NYCDEP-DSGEIScomments122209.pdf.
[1461] New York City Department of Environmental Protection, "Comments on the Revised Draft Supplemental Generic Environmental Impact Statement," January 11, 2012.
[1462] New York City Department of Environmental Protection, "Comments on the Revised High-Volume Hydraulic Fracturing Regulations," November 30, 2012.

events near fracking operations in the Horn River Basin. The report noted that no quakes had been recorded in the area prior to April 2009, before fracking began. The report recommended that the link between fracking and seismic activity be further examined.[1463]

- March 29, 2012 – The USGS found that between 2001 and 2011, there was a six-fold increase in earthquakes greater than magnitude 3.0 in the middle of the United States that "are almost certainly manmade." The agency further reported that the increase appears to be linked to oil and gas production and deep injection of drilling wastewater.[1464, 1465]

- July 31, 2011 – Numerous earthquakes in Arkansas motivated the Arkansas Oil and Gas Commission to shut down a disposal well and enact a permanent moratorium on future disposal wells in a nearly 1,200 square-mile area of the Fayetteville Shale.[1466]

- March 10, 2010 – In Texas, a 2008-2009 swarm of earthquakes in the Dallas-Fort Worth area was linked to produced water disposal wells.[1467]

- June 12, 2009 – *The Wall Street Journal* reported that earthquakes shook Cleburne, Texas, a small town at the epicenter of fracking activity. More earthquakes were detected during that period of fracking activity than in the previous 30 years combined.[1468]

[1463] The Canadian Press, "Fracking Causes Minor Earthquakes, B.C. Regulator Says," *CBC News*, September 6, 2012, https://www.cbc.ca/news/canada/british-columbia/fracking-causes-minor-earthquakes-b-c-regulator-says-1.1209063.
[1464] William L. Ellsworth et al., "Are Seismicity Rate Changes in the Midcontinent Natural or Manmade?," 2011, https://www.researchgate.net/publication/281538802_Are_seismicity_rate_changes_in_the_midcontinent_natural_or_manmade_Abstract.
[1465] Mike Soraghan, "'Remarkable' Spate of Man-Made Quakes Linked to Drilling, USGS Team Says," *E&E News*, March 29, 2012, https://web.archive.org/web/20130708085615/http://www.eenews.net/stories/1059962190.
[1466] Caroline Zilk, "Permanent Disposal-Well Moratorium Issued," *Arkansas Online*, July 31, 2011, https://www.arkansasonline.com/news/2011/jul/31/permanent-disposal-well-moratorium-issued-20110731/.
[1467] C. Frohlich et al., "The Dallas-Fort Worth Earthquake Sequence: October 2008 through May 2009," *Bulletin of the Seismological Society of America* 101, no. 1 (2011): 327–40, https://doi.org/10.1785/0120100131.
[1468] Ben Casselman, "Temblors Rattle Texas Town," *Wall Street Journal*, June 12, 2009, sec. Business, https://www.wsj.com/articles/SB124476331270108225.

Abandoned and active wells as pathways for gas and fluid migration

Individually or together, abandoned and active wells can serve as underground conduits for the migration of fluid and vapors. The most probable pathway of contaminant transport takes place outside the well casing, allowing leaks to migrate upward within the well, contaminating soil or groundwater and emitting methane into the atmosphere. A 2020 investigation in Pennsylvania identified uncemented sections of well casings as the most common cause of water contamination incidents.

The proportion of active wells that leak gas and fluids is unknown, but a 2021 study that examined the records of more than 100,000 oil and gas wells in three states estimates an overall leakage of 14.4 percent with fracked and horizontal wells showing a higher frequency of leaks than vertical wells (30.3 percent versus 11 percent). The cost of remediating fracked wells at the end of their lifespan is also significantly higher than for conventional wells, with costs that can exceed $100,000 per well.

Most fracking operations take place in oil and gas fields with a long history of conventional drilling and therefore with many abandoned wells. Multiple lines of evidence reveal that abandoned wells can and do allow pressurized fluids and gases to migrate to the surface and, in some cases, intersect active wells. Whether plugged or unplugged, abandoned wells are a significant source of methane leakage into the atmosphere and, based on findings from New York and Pennsylvania, may exceed cumulative total leakage from oil and gas wells currently in production. No state or federal agency routinely monitors methane leakage from abandoned wells. A 2021 study found that annual methane emissions from abandoned oil and gas wells might be underestimated by as much as 150 percent in Canada and 20 percent in the United States. A 2022 study of methane leaks from more than 2,500 wells in northern Colorado found widespread well casing failures throughout the region.

The location and status of most abandoned wells are not recorded in state databases, and many remain unplugged. Of the approximately 4,700,000 oil and gas wells in the United States, close to 3 million are no longer in production and an estimated 2.6 million are unplugged. These numbers are likely underestimates because of poor recordkeeping. As many as 750,000 to 1 million abandoned wells are orphaned: their owners either cannot be located at all or are unable pay the costs of decommissioning them. In Pennsylvania alone, 24,619 wells are documented as abandoned with an additional estimated 200,000 wells orphaned and unaccounted for in state records. In California, 5,540 wells are orphaned or at high risk of becoming orphaned. In the United States, the number of abandoned wells increased by over 12 percent since the onset of the fracking boom in 2008. The number of orphaned wells in the United States is expected to increase as the economy transitions to renewables.

$300 billion is the estimated cost of cleaning up and remediating of the entire U.S. inventory of abandoned wells. This cost is likely to rise, according to a 2021 analysis, as newer abandoned wells tend to be fracked wells which are much deeper and more difficult and expensive to remediate.

Most abandoned wells are not adequately bonded, leaving the full cost of plugging them to state or federal taxpayers. The financial stress of continued low prices led to a 50 percent rise in bankruptcies in 2019 and a further increase in orphaned wells. Also in 2019, the U.S. Government Accountability Office (GAO) reported that 84 percent of bonds for extraction of oil and gas on federal lands were insufficient to cover cleanup costs. The federal Bureau of Land Management (BLM) lacks good methods for tracking idle oil and gas wells drilled on public lands, and funding is inadequate to plug those orphaned wells which have already been identified.

- May 29, 2023 – A University of California, Santa Barbara team undertook a critical analysis of the world's estimated 29 million abandoned oil and gas wells, focusing on the challenges for decommissioning them. The issue has both global and local consequences. Globally, abandoned wells emit over 2.5 million tons of methane annually, while the toxic chemicals associated with them contaminate local air and water. In the United States, 14 million people live within one mile of an abandoned or orphaned well and these wells are often located near marginalized communities. No national database of well locations exists in the United States, and historical records of old wells are incomplete. As more abandoned wells continue to be discovered and as new wells continue to be drilled, the number of wells requiring decommissioning continues to rise. The process of decommissioning is expensive. In California, for example, the average cost to plug an orphan well is $68,000. The research team found that the surety bonds required of corporations to cover these costs are typically inadequate and that corporations often use evasion tactics such as offloading liabilities, shell companies, and bankruptcy to avoid responsibility. The costs of decommissioning thus often falls to taxpayers. The authors recommend the development of long-term plans for decommissioning fossil fuel infrastructure as an important facet of a transition to clean energy. These plans should include addressing corporate responsibility, funding, ongoing monitoring of decommissioned wells, and improving the database of orphaned and abandoned wells.[1469]

- May 19, 2023 – A chemical analysis of the gaseous emissions from 48 abandoned wells (8 plugged and 40 unplugged) in western Pennsylvania found frequent detections of benzene and other volatile organic compounds (VOCs), including hexane, cyclohexane, and heptane. Benzene, toluene, and xylene levels were significantly higher than the California Chronic Reference Exposure levels, with the health risk dominated by benzene (a known carcinogen). The rate of emission of VOCs depended on the flow rate of the gas stream and the concentration of VOCs in the gas. Carbon monoxide was detected in 19 percent of wells, and hydrogen sulfide was detected at some, suggesting that abandoned wells should be routinely screened for those gases. Gas was detectable at the ground surface for 11 percent of tested wells, indicating that measurements should be made both before and after remediation. According to a proximity analysis, almost 41 percent of abandoned wells in Allegheny County, Pennsylvania were located within 100 meters of a residence, with some much closer. The authors recommend further studies to

[1469] Tristan Partridge et al., "Decommissioning: Another Critical Challenge for Energy Transitions," *Global Social Challenges Journal*, May 29, 2023, 1–15, https://doi.org/10.1332/NNBM7966.

determine whether emissions from abandoned oil and gas wells pose a health risk to people living near them. According to Pennsylvania Department of Environmental Protection records, 24,619 abandoned oil and gas wells are scattered across the state; another estimated 200,000 abandoned and orphaned wells are undocumented and unrecorded.[1470]

- March 9, 2023 – As part of the NASA Arctic-Boreal Vulnerability Experiment (ABoVE), which examines the vulnerability and resilience of ecosystems in Alaska and Western Canada, a team of researchers examined the impacts of the region's 242,007 documented oil and gas wells. Database analysis indicates that 63 percent of wells are abandoned and 19 percent remain unplugged. The permafrost, present in most of that area, is thawing. The resulting changes in landform may further compromise well integrity. Methane emissions in the ABoVE domain were estimated to be more than 200 percent higher than Canadian Greenhouse Gas Reporting Program estimates and collectively represented about 30 percent of total Canadian anthropogenic methane emissions. Oil and gas activities may also be contributing to loss of evergreen forest. The wide range of estimates of methane emissions in this study indicate a need for better evaluation of abandoned oil and gas wells in this region, including verification of site locations and improvement of well databases.[1471]

- March 6, 2023 – A critical review of the available literature on emissions from both abandoned and active oil and gas wells sought to evaluate factors that can affect leakage and consider options for remediation. Conventional and fracked wells were not separately considered. Variables that consistently affect leakage included production type (conventional vs. unconventional), well location, plugging status, reservoir pressure, and deviation of the wellbore. Regulations regarding monitoring and plugging of inactive and abandoned wells varied across Canada and the United States, and these are often not enforced. The authors recommend strictly enforced regulations regarding monitoring and repair of leakage and stricter timelines for plugging abandoned wells. Studies across wider geographic areas were also recommended.[1472]

- January 24, 2023 – In Pennsylvania, a state law directs how federal funds for oil and gas well plugging should be used, but the same law disallows the Environmental Quality Board from setting bonding requirements for conventional wells. As part of an investigation prompted by this law, the Pennsylvania Department of Environmental Protection found that conventional well operators frequently ignore state laws requiring them to report information about the status of their wells without consequence and that 3,000 newly abandoned wells over the past five years remain unplugged. Other

[1470] Dominic C. DiGiulio et al., "Chemical Characterization of Natural Gas Leaking from Abandoned Oil and Gas Wells in Western Pennsylvania," *ACS Omega*, May 19, 2023, acsomega.3c00676, https://doi.org/10.1021/acsomega.3c00676.
[1471] Louise A Klotz et al., "Oil and Natural Gas Wells across the NASA ABoVE Domain: Fugitive Methane Emissions and Broader Environmental Impacts," *Environmental Research Letters* 18, no. 3 (March 1, 2023): 035008, https://doi.org/10.1088/1748-9326/acbe52.
[1472] Khalil El Hachem and Mary Kang, "Reducing Oil and Gas Well Leakage: A Review of Leakage Drivers, Methane Detection and Repair Options," *Environmental Research: Infrastructure and Sustainability* 3, no. 1 (March 1, 2023): 012002, https://doi.org/10.1088/2634-4505/acbced.

unreported violations included drilling fluid spills. The cost to decommission and plug one well in Pennsylvania is $30,000. The state has an estimated 200,000 wells to decommission, indicating a massive financial risk not compensated by the current bonding requirements.[1473, 1474]

- November 15, 2022 – The surface casing of an oil or gas well is a steel pipe around the well forming a barrier to fluid migration and extending below the lowest level of potable groundwater. Measurements of casing pressure and casing vent flow at the surface are indicators of well casing integrity and can help assess the potential for environmental contamination. A research team led by the U.S. Department of Energy's National Energy Technology Laboratory analyzed geochemical samples collected from the surface casings of 2,573 wells in northern Colorado as part of a publicly available dataset. Available carbon isotope analysis enabled the research team to assess whether the surface gas originated from microbes (biogenic origin) or from deep geological strata (thermogenic origin). The results showed that the methane leaking from the surface casing was thermogenic, indicating that its origin was a subsurface reservoir. Furthermore, benzene, toluene, ethylbenzene, and xylenes (BTEX) exceeding the EPA maximum contaminant level were found in almost all samples tested for those compounds. Assessment of possible gas migration pathways indicated that "gas migration into the surface casing annulus predominantly occurs through compromised barriers (e.g., steel casings or cement seals), indicative of extensive integrity issues in the region." The authors recommend monitoring and correcting elevated surface casing pressures to avoid release of subsurface gas and fluids.[1475]

- August 22, 2022 – The United States Geological Survey created a publicly available database of 117,672 unplugged, orphan oil and gas wells across 27 different states. This database includes location coordinates and well type (i.e. oil, gas, or both). The definition of "inactive" varies by state, ranging from 6 to 24 months of lack of production. Orphaned, in this context, signifies that a party responsible for management of the well cannot be located. There is no distinction between conventional and fracked wells in this dataset.[1476]

- February 3, 2022 – A McGill University research team evaluated methane and hydrogen sulfide emissions from 63 oil and gas wells in Ontario, Canada. The wells were classified according to their production status as abandoned, marginally producing, or active. A wetland area over a possible undocumented well was also tested. The results showed that

[1473] Rachel McDevitt, "Pa. Drillers Abandoned Thousands of Natural Gas Wells in 5 Years, Ignored State Law, Report Says," *State Impact Pennsylvania*, January 24, 2023, https://stateimpact.npr.org/pennsylvania/2023/01/24/pa-drillers-abandoned-thousands-of-natural-gas-wells-in-5-years-ignored-state-law-report-says/.
[1474] Pennsylvania Department of Environmental Protection, "Executive Summary," n.d., https://files.dep.state.pa.us/OilGas/BOGM/BOGMPortalFiles/Governor's_Lapsing_Statement_Report_2022-12-29.pdf.
[1475] Greg Lackey et al., "Composition and Origin of Surface Casing Fluids in a Major US Oil- and Gas-Producing Region," *Environmental Science & Technology* 56, no. 23 (December 6, 2022): 17227–35, https://doi.org/10.1021/acs.est.2c05239.
[1476] Claire A Grove and Matthew D Merrill, "United States Documented Unplugged Orphaned Oil and Gas Well Dataset" (U.S. Geological Survey, 2022), https://doi.org/10.5066/P91PJETI.

wells emitting hydrogen sulfide also emitted methane at the highest rates. Hydrogen sulfide is highly corrosive and has the potential to deteriorate wellbore cement and steel. The next highest methane emitters were marginal and unplugged, abandoned wells. Abandoned plugged wells were the lowest emitters, but the team noted that the average methane emission from those wells nevertheless markedly exceeded that reported in the Canadian National Inventory Report. That report also appeared to underestimate active and marginal well emissions. Recommendations include further studies to determine the true number of undocumented wells in Canada and more regulatory oversight to ensure well monitoring , licensing, and plugging.[1477]

- October 16, 2021 – Working in British Columbia, an international research team simulated a well integrity failure in order to characterize surface methane emissions from gas migration in a structurally compromised well. Researchers synthesized a gas that matched the composition of the gas in the underlying shale basin and injected it at a constant rate 26 meters below the surface at the base of an aquifer, to simulate a well casing integrity failure. Gas migration at the surface was measured in 12 chambers as well as by eddy-covariance flux of atmospheric methane. Soil gas was collected at 22 monitoring wells. As an incidental finding, one of the monitoring wells provided an unexpected pathway for gas migration. Approximately 25 percent of the injected gas was detected as surface emissions even though the immediate subsurface soil had low permeability. The research team documented that subsurface gas was able to migrate against the direction of groundwater flow. Most of the injected gas remained confined underground, suggesting the possibility of risk to groundwater.[1478]

- July 14, 2021 – An economic analysis by the U.S. non-profit organization Resources for the Future provided cost estimates for decommissioning the nation's more than 2.1 million non-producing but unplugged oil and gas wells. The authors note that decommissioning is an expensive, multi-step process that involves not only plugging the wellbore but also removing equipment and restoring the well pad. Factors affecting the full cost of plugging and reclamation included well depth, well age, and the surrounding topography. Bonding requirements prior to drilling are inadequate to cover the full costs of decommissioning. Hence, well operators often declare bankruptcy or cannot be located, leaving taxpayers to foot the bill. Analyzing data from over 19,500 oil and gas wells, the study found that the median costs for plugging only was $20,000 but the full decommissioning cost, including surface reclamation, was $75,000 per well. "Each additional 1,000 feet of well depth increases costs by 20%, older wells are more costly than newer ones, natural gas wells are 9% more expensive than wells that produce oil, and costs vary widely by state. Surface characteristics also matter: each additional 10 feet of elevation change in the 5-acre area surrounding the well raises costs by 3%." The authors suggest that bonding requirements could be improved by accounting for these

[1477] Khalil El Hachem and Mary Kang, "Methane and Hydrogen Sulfide Emissions from Abandoned, Active, and Marginally Producing Oil and Gas Wells in Ontario, Canada," *Science of The Total Environment* 823 (June 2022): 153491, https://doi.org/10.1016/j.scitotenv.2022.153491.
[1478] Julia V. Soares et al., "Towards Quantifying Subsurface Methane Emissions from Energy Wells with Integrity Failure," *Atmospheric Pollution Research* 12, no. 12 (December 2021): 101223, https://doi.org/10.1016/j.apr.2021.101223.

factors and that decommissioning costs could be improved somewhat by "contracting in bulk." Site surface restoration adds considerably to cost, but is estimated to add ecosystem service benefits of approximately $49,000 per well.[1479]

- July 1, 2021 – As reported in the *Los Angeles Times*, an analysis by the National Parks Conservation Association (NCPA) identified almost 32,000 orphaned oil and gas wells within 30 miles of national parks nationwide. They are not productive, have not been properly plugged, and the owners are bankrupt or cannot be found. An interactive map of national parks and orphaned wells shows that about 5,700 of these wells are near the Santa Monica Mountains National Recreation Area. These leaky wells contribute to poor air quality, and aside from contributing to climate change, increase the threat of wildfires, contaminate aquifers, and harm the ecosystem. About 120,000 jobs could be created by the federal government by a national program to plug orphaned wells, potentially keeping oil and gas workers employed during the switch to renewables. And yet, as America Fitzpatrick, energy program manager at NPCA, noted, such public works projects represent indirect subsidies to the oil and gas industry. "It's really unfortunate that the American taxpayer has (had) to address the cleanup that these oil and gas companies should really be responsible for."[1480]

- June 25, 2021 – An analysis in the California newspaper *Desert Sun*, explicates how companies use bankruptcy protection to shift the clean-up costs of abandoned wells to taxpayers. Oil and gas companies are required to put up bonds for cleanup prior to the onset of drilling, but the required amounts are often grossly inadequate to cover the costs. Companies have no incentive to spend more money, and essentially walk away. Since 2015, over 260 oil and gas companies have filed for chapter 11 bankruptcy in North America, essentially reaping the profits of fossil fuel extraction but leaving the responsibility and costs to state and federal governments. Only $110 million in bonding has been set aside for remediating California's depleted oil and gas wells, while the cleanup costs are estimated to be in the billions. California state Senator Monique Limon commented that the problem of companies leaving California with a cleanup bill "absolutely is a systemic issue." Rincon Island, an artificial island built in the 1950s to drill for oil is a case in point. It has not produced oil since 2008, has been cited for multiple violations, and has changed hands many times. Purchased in 2002 in a bankruptcy sale, the buyer then filed for bankruptcy and taxpayers were left with a $27 million tab.[1481]

- May 10, 2021 – Since the mid-1880s, over one quarter million wells have been drilled in Ohio. Identifying which ones have been properly plugged and which should be deemed

[1479] Daniel Raimi et al., "Decommissioning Orphaned and Abandoned Oil and Gas Wells: New Estimates and Cost Drivers," *Environmental Science & Technology* 55, no. 15 (August 3, 2021): 10224–30, https://doi.org/10.1021/acs.est.1c02234.
[1480] Sammy Roth, "How Many Abandoned Oil Wells Threaten Your Favorite National Park?," *Los Angeles Times*, July 1, 2021, https://www.latimes.com/environment/newsletter/2021-07-01/how-many-abandoned-oil-wells-threaten-your-favorite-national-park-boiling-point.
[1481] Mark Olalde, "Oil Bankruptcies Leave Environmental Cleanup Bills to California Taxpayers," *Desert Sun*, June 25, 2021, https://www.desertsun.com/in-depth/news/environment/2021/06/25/oil-bankruptcies-leave-environment-cleanup-california-taxpayers/4977647001/.

orphans is difficult work. Many are found only after problems are reported. For example, one old well was discovered under the gym floor of an Ohio elementary school. Magnetometers mounted on drones can scan a large area and identify anomalies in the ground's magnetic field that signify the presence of a vertical well casing. In a recent study, this technique located almost 90 possible wells in an area where records had indicated only 39. Not all old wells retain their original metal casings; in these cases, the use of LIDAR (LIght Detection And Radar) technology may be needed. Ohio hopes to use these both techniques to identify orphan wells and is also planning to increase the rate of plugging them. The Ohio Department of Natural Resources has set a goal of locating and plugging at least 200 depleted wells a year, but, at this pace, hundreds of years would be required to plug all of them. Use of high-tech tools like magnetometers and drones could help by identifying wells nearby to an existing remediation site, thereby allowing contractors to batch plugging jobs together. According to proponents of this plan, plugging Ohio's abandoned wells could create at least 8,000 jobs over a 20-year period, a cost-effective measure that brings ecosystem benefits, especially when weighed against the social costs of greenhouse gas emissions.[1482]

- May 7, 2021 – In early 2020, Canada allocated $1.7 billion in federal funding to clean up orphaned and inactive oil and gas wells owned by companies that were financially incapable of doing so. The province of Alberta alone received $1 billion. An investigation by a nonprofit news organization, the *Narwhal*, found that half of the funding went to help clean up sites owned by eight of Canada's largest oil and gas companies. Sites owned by Canadian Natural Resources Limited were allocated over $102 million, despite the company having reported an average of $1.9 billion in annual net profits over the last decade and having increased shareholder dividends by 11 percent in March 2021. Among other findings: bonds required of companies in Alberta to ensure adequate funding of cleanup are inadequate, and no legislation indicates when wells must be sealed. Further, the current estimated cost of cleanup is about $30 billion, but only $216 million in bonds are held for this purpose. Morrigan Simpson-Marran, an analyst with the Pembina Institute, has urged a redirection of federal money to help smaller companies address their orphan well problem and regulations requiring larger companies to clean up their own wells.[1483]

- May 2, 2021 – A proposed $30 million project to plug 1,600 oil wells in Pennsylvania's Allegheny National Forest has been plagued with delays, possible fraud, and allegations of criminal felonies. Resources Preservation, legally responsible for plugging the wells, created a partnership with AquaPower Holdings, which has floated a complex plan that requires the purchase of a decommissioned power plant and wastewater treatment facility. Sand would be transported in one direction, and salt would be transported back. Coal fly ash would be mixed into concrete to be used for new roads and well pads, while fracking wastewater would be turned into road salt and other salable products that would

[1482] Kathiann M. Kowalski, "Thousands of Abandoned Ohio Oil and Gas Wells May Be Hidden. Drones Could Help Find Them," *Energy News Network*, May 10, 2021, https://energynews.us/2021/05/10/thousands-of-abandoned-ohio-oil-and-gas-wells-may-be-hidden-drones-could-help-discover-them/.
[1483] Sharon J. Riley, "$100 Million in Federal Funding for Cleanup of Alberta Oil and Gas Wells Went to Sites Licensed to CNRL," *The Narwhal*, May 7, 2021, https://thenarwhal.ca/cnrl-alberta-oil-gas-wells-cleanup/.

then pay to plug old wells. The legal agreement with the Pennsylvania Department of Environmental Protection (DEP) required Resources Preservation to plug at least 10 wells and return 60 abandoned wells to production by the end of 2020. However, 15 months after the agreement, there has been no progress, and Resources Preservation has stated that it lacks financial resources to proceed, and blames AquaPower, which has not made required payments to Resources Preservation totaling $600,000. The state of Pennsylvania has subpoenaed financial records and plans to use forensic accountants to evaluate the issue. Financial hardship does not excuse the company from its obligations, as noted by EPA enforcement officer Leah Zedella. "Compliance with the Safe Drinking Water Act is required without contingencies." At the time of publication Resources Preservation had plugged only one well and paid for it by selling equipment.[1484]

- April 28, 2021 – There are approximately 4,700,000 oil and gas wells in the United States and 790,000 in Canada. About 60 percent of these are inactive but only one in three of the inactive wells are plugged. The number of wells no longer in production is likely an underestimate because of poor recordkeeping of older wells. Inactive wells pose environmental hazards related to air pollution, greenhouse gas emissions, groundwater contamination, and ecosystem damage. They can leak underground even if there is no surface leak and substances may reach the surface through complex pathways. The number of orphaned wells, which are abandoned wells for which no responsible party exists, is expected to increase as the economy transitions to renewables. This study evaluated oil and gas data from the United States and Canada in order to identify policies that could address environmental problems related to inactive wells. It identified barriers to plugging and the potential for leaks, and urged further research on the potential for plugged wells to leak. Oil and gas industry bonds for well-plugging and site restoration are inadequate, and possible additional sources of funding, such as carbon credits and repurposing land for wind and solar, can augment these. The benefits of well-plugging when including carbon pricing, the social cost of greenhouse gas emissions, and restoration of ecosystem impacts could offset much of the cost. The authors provide a list of policy recommendations for monitoring and managing abandoned wells and recommend further studies on the environmental impacts of abandoned wells and plugging.[1485]

- April 25, 2021 – An analysis of financial inequity related to oil and gas wells at the end of their productive lifespans described the ways in which the cost of clean-up is transferred to taxpayers. When production at an oil or gas well falls, a large corporation often will sell it to a smaller one, along with the responsibility for cleanup. Bonds are required to cover the cost of clean-up prior to drilling but in most states the bonds cover only about two percent of the actual clean-up cost. Companies are also allowed to buy "blanket bonds," which allow an unlimited number of wells for one price. When

[1484] Anya Litvak and Laura Legere, "Project to Plug 1,600 Oil Wells in Allegheny National Forest Faces Delays, Doubt — Even an Arrest Warrant," *Pittsburgh Post-Gazette*, May 2, 2021, https://www.post-gazette.com/business/powersource/2021/05/02/A-project-to-plug-1-600-wells-is-almost-ready-to-launch-and-has-been-for-six-years/stories/202105020101.
[1485] Mary Kang et al., "Orphaned Oil and Gas Well Stimulus—Maximizing Economic and Environmental Benefits," *Elementa: Science of the Anthropocene* 9, no. 1 (2021), https://doi.org/10.1525/elementa.2020.20.00161.

production falls below profitability, many smaller companies find it easier to file for bankruptcy or leave the state rather than clean up. This is the point at which the cost of cleanup falls to taxpayers. For example, the estimated cost of plugging all orphaned wells in Louisiana is now over $200 million. An Abandoned Well Act that would create a federal Abandoned Well Administration and set realistic bonding requirements may be necessary. In addition, the author suggests that oil and gas companies should start paying now for their prior 150 years of damage to the environment.[1486]

- April 16, 2021 – Oil and gas companies are attempting to sell off over $110 billion worth of assets to compensate for financial losses in 2020 and to show apparent reductions of their carbon footprints. Regulations regarding the decommissioning and environmental liabilities of offshore assets are tougher than onshore; selling an offshore asset does not relieve a company from the responsibility of the cost of decommission as it does with onshore wells. This discrepancy has caused sale prices of offshore assets to fall significantly. For example, Exxon sold its North Sea assets for only half of the original price, likely related to the high projected cost of decommissioning. Onshore rules for decommissioning wells are, by contrast, much more lax, allowing gas and oil companies to simply abandon unprofitable wells, leaving taxpayers on the hook for the cost of decommissioning.[1487]

- April 14, 2021 – An analysis of President Biden's plan to plug orphaned oil and gas wells estimated the number of documented unplugged well at 2.6 million with another 1.2 million undocumented unplugged wells. The cost for cleaning up all of them could reach $300 billion. Further, this cost is likely to rise, as newer abandoned wells tend to be fracked wells which are much deeper and more difficult to remediate. States require bonds to cover the cost of well plugging, but estimates suggest that the required bonds would cover only about one percent of cleanup costs. Companies therefore frequently abandon the wells when production falls and taxpayers are left with the bill. The American Jobs Plan would invest $16 billion to begin cleanup of orphaned wells, but the ongoing concern is how to avoid creating incentives for more well abandonment. Proposals are under consideration to add stricter financial requirements for oil and gas producers that would limit the likelihood of well abandonment.[1488]

- April 6, 2021 – The proportion of active gas and oil wells in the United States that leak is unknown. Fluid leaks can migrate upward within the well, often through a poorly cemented well annulus, contaminating soil or groundwater and emitting methane. A team of researchers investigating the frequency of leaks in active oil and gas wells looked at oil and gas regulatory databases of 33 states but were only able to obtain adequate information for analysis from three: Colorado, New Mexico and Pennsylvania. From the

[1486] Bob Marshall, "Oil Companies Made a Mess. Will Taxpayers Clean It Up?," Nola.com, April 25, 2021, https://www.nola.com/opinions/article_e3d315b4-a3bb-11eb-8acc-7b0a5eebdbdb.html.
[1487] Justin Mikula, "Fossil Fuel Companies' Tough Sell: Oil and Gas Sites with Costly Environmental Clean-Up," *DeSmog*, April 16, 2021, https://www.desmog.com/2021/04/16/fossil-fuel-companies-tough-sell-oil-gas-sites-environmental-clean-up/.
[1488] Alexander Sammon, "Biden's Promising, Problematic Plan to Plug Orphaned Oil and Gas Wells," *The American Prospect*, April 14, 2021, https://prospect.org/environment/bidens-promising-problematic-plan-plug-orphaned-oil-gas-wells/.

records of these three states, the team created a dataset of almost 475,000 tests of leakage on over 105,000 oil and gas wells. These tests were of two types: sustained casing pressure (SCP) tests and casing vent flow (CVF) tests of well integrity. SCP testing is done by measuring annular pressure buildup after an initial "bleeding off" of pressure, whereas CVF testing involves observation for leakage through an open annular valve. By combining these records, the researchers estimated that 14.4 percent of the tested wells had exhibited leakage. Deviated or horizontal wells showed a higher frequency of leaks than vertical wells (30.3 percent versus 11 percent). A combination of well construction information and SCP testing was used as a proxy to identify wells with a potential for gas migration into groundwater. The findings indicated that directional wells were more likely than vertical ones to have a potential for gas migration in Colorado and Pennsylvania, although this pattern was not seen in New Mexico and was less apparent in Pennsylvania for wells drilled after 2011. The dataset included only about 10 percent of the active wells in the United States. The authors suggest a standardized testing protocol to identify well integrity issues and allow better planning of remediation or abandonment of wells.[1489]

- March 19, 2021 – British Columbia has dedicated a $100 million fund to clean up dormant oil and gas wells. The funds cover 50 percent of the cost of restoration, up to $100,000 per well. An investigation by *The Tyee* found that much of the money is going to financially secure major oil and gas companies. One quarter of the first $50 million will be used to clean up sites owned by Canadian Natural Resources, Ltd, a company worth $45 billion. Shanghai Energy Corp., of which the Chinese Communist Party has an ownership stake, is another recipient of funding. Supporters of this plan highlight job creation and environmental benefits. Critics argue that companies benefiting from oil and gas extraction in British Columbia should be fully responsible for cleaning up their sites.[1490]

- January 29, 2021 – No U.S. federal regulations govern the remediation of orphaned wells, a task that falls to state governments. A study of how states manage this problem examined underlying factors that influence state policies regarding the financial risks of abandoned and orphaned wells. The researchers tested combinations of five variables, including the adequacy of bonding requirements and the use of fees and taxes to cover the costs. They added the state governor's party as well as the Forbes Green Index and the stringency of state oil and gas regulations regarding oil and gas production to the assessment. Binary values were assigned to the variables and ordinary least squares regression was used to correlate them. The findings showed that that states with more restrictive oil and gas rules and which are less reliant on oil and gas revenues had stronger financial assurance policies. There was no correlation with the state governor's political party or with anticipated cleanup costs. Overall, their model accounted for about 60 percent of the variability between states. The authors recommend avenues for future

[1489] Greg Lackey et al., "Public Data from Three US States Provide New Insights into Well Integrity," *PNAS* 118, no. 14 (2021), https://doi.org/10.1073/pnas.2013894118.
[1490] Andrew MacLeod, "Governments Are Making Taxpayers Subsidize Corporate Cleanup of Oil and Gas Wells," *The Tyee*, April 19, 2021, https://thetyee.ca/News/2021/03/19/Governments-Make-Taxpayers-Subsidize-Corporate-Cleanup-Oil-Wells/.

research, including better data collection and reporting of the number of orphan wells and the costs of remediation. Notably, the cost of remediating orphaned and abandoned oil and gas wells is much higher for fracked wells and can exceed $100,000 per well.[1491]

- January 12, 2021 – Writing in *Current Affairs*, energy market analyst Megan Milliken Biven proposed the development of a national Abandoned Well Administration to directly employ displaced oil and gas workers, to identify and remediate the millions of abandoned wells in the United States, and to establish a national monitoring and safety response program. She also recommended the establishment of an abandoned well tax on all well owners to begin paying for cleanup. The cost of plugging and site remediation is high; an estimated $280 billion would be needed to properly plug the 2.6 million documented wells in the United States. With a lack of federal oversight, oil and gas companies strongly influence local tax and zoning laws and the cost of bonding required to clean up wells at the end of their productive life. Companies often avoid the cost of plugging by delaying abandonment or by offloading the wells to smaller firms, which are less likely to afford well closures. Taxpayers end up shouldering the costs in violation of the "polluter pays" principle. An Abandoned Well Administration would also redress a humanitarian issue arising from the failure to link federal allocations to clean up wells with requirements to hire or retain workers. In Louisiana, prisoners are used by the oil and gas industry for this purpose and work long hours for minimal pay.[1492]

- January 3, 2021 – An historical analysis of oil and gas records in Michigan, where drilling began in 1859, showed that about 60,000 oil and gas wells have been drilled in the state, with the location of many older wells unknown and the number of orphaned wells growing, similar to the situation across the United States. Michigan regulations require oil and gas companies to notify the Michigan Department of Environment, Great Lakes, and Energy about non-producing or dry wells and to pay for plugging themselves. The agency also administers specific plugging instructions for each well. The process is expensive, but blanket bonds for cleanup at well end-of-life, covering all of a company's wells in the state, range from $100,000 to $250,000. This amount is grossly inadequate. A 2017-2018 orphaned well report indicated that it cost Michigan over $1 million to plug just six wells in difficult locations. An orphan well fund in Michigan collects two percent of a severance tax from the oil and gas industry but these funds are also insufficient to cover the cost of plugging. Michigan regulators, as opposed to most other states, have the authority to examine the receiving company's assets to see if they would have the ability to pay for remediation. This makes it much harder for oil and gas companies to walk away from financial responsibility in the state. Municipalities in Michigan are not allowed to pass zoning laws limiting drilling, and the state requires a setback of only 1,320 feet from homes.[1493]

[1491] Steven Nelson and Jonathan M. Fisk, "End of the (Pipe)Line? Understanding How States Manage the Risks of Oil and Gas Wells," *Review of Policy Research* 38, no. 2 (2021): 203–21, https://doi.org/10.1111/ropr.12411.
[1492] Megan Milliken Biven, "The Wreckage of the Last Energy Epoch: Abandoned Wells and Workers," *Current Affairs*, July 12, 2021, https://www.currentaffairs.org/2020/01/the-wreckage-of-the-last-energy-epoch-abandoned-wells-and-workers/.
[1493] Stacy Gittleman, "'Orphaned' Oil, Gas Wells and Threat to the Climate," *Downtown News Magazine*, January 3, 2021, https://www.downtownpublications.com/single-post/orphaned-oil-gas-wells-and-threat-do-the-climate.

- December 15, 2020 – A McGill University team collected data on methane emissions from almost 600 abandoned wells in the United States and Canada, across seven states and two provinces, and used estimates of the number of abandoned wells in both countries to extrapolate a cumulative total of methane leakage from this source. Regional variations, plugging status, and well type (gas, combined oil and gas, and unknown) were considered in the analysis, and five different scenarios were used to see how different approaches would affect the estimates. The results showed that 96 percent of cumulative emissions come from 10 percent of wells, with unplugged gas wells serving as the highest emitters. Abandoned gas wells emitted almost double the emissions of abandoned combined oil and gas wells. The findings indicate that, for both the United States and Canada, methane emissions from abandoned wells are significantly higher than previously estimated (by 20 percent in the United States and by as much as 150 percent in Canada) and that there remains a great deal of uncertainty about the actual quantity of these emissions. Less than 0.01 percent of abandoned oil and gas wells in the United States and Canada have been measured for leakage, and the actual number of such wells also remains unclear. These results also suggest that emissions could be markedly reduced by plugging abandoned wells and by locating "super emitters."[1494, 1495] Commenting on the study, David Risk, a professor of earth sciences at St. Francis Xavier University said, "But if there's one thing that oversight studies have taught us, it's that when we measure more, we often find more. I think there's a strong possibility that emissions are larger than expressed here."[1496]

- October 30, 2020 – California has over 124,000 abandoned oil and gas wells and 38,000 so-called idle wells: unplugged wells that have not produced oil or gas for two more years. The wells can continue to leak methane, which is not only a climate threat but presents an explosion risk and can contaminate groundwater. Methane is also involved in the formation of ozone, and benzene and toluene can be co-contaminants. A research team evaluating methane emissions from abandoned wells in California used a combination of methods that allowed more sensitive measurements than those collected by the California Methane Survey. Looking at a representative sample of abandoned oil and gas wells in California, the researchers found a wide range of leakage rates, with unplugged idle wells leaking more than plugged abandoned wells and with the worst culprits leaking enough to substantially impact California's methane budget. Extrapolating the data suggests that the leakage rate might increase the California Methane Survey's estimate of emissions by 31 percent. The authors recommend further

[1494] James P. Williams, Amara Regehr, and Mary Kang, "Methane Emissions from Abandoned Oil and Gas Wells in Canada and the United States," *Environmental Science & Technology* 55 (2021): 563–70, https://doi.org/10.1021/acs.est.0c04265.
[1495] James P. Williams, Amara Regehr, and Mary Kang, "Correction to "Methane Emissions from Abandoned Oil and Gas Wells in Canada and the United States"," *Environmental Science & Technology* 55 (2021): 3449–3449, https://doi.org/10.1021/acs.est.0c04265.
[1496] Natasha Bulowski, "Canada Needs to Plug Methane Pollution from Abandoned Wells," *National Observer*, May 10, 2021, https://www.nationalobserver.com/2021/05/10/news/canada-needs-more-data-abandoned-oil-and-gas-wells.

samples of idle and active wells at a low detection limit and additional measurements in areas where groundwater pumping has caused high levels of subsidence.[1497]

- August 10, 2020 – "Stripper" wells are oil or gas wells near the end of their lifespans that produce less than 15 barrels of oil equivalent. They are typically not profitable to operate but, because the cost of decommissioning them can be greater than the cost of keeping them running, they remain online or at the ready. Stripper wells are the most abundant type of oil and gas well, with more than 700,000 of these low-producing, marginal wells in the United States, and they appear to represent a disproportionately large source of methane emissions relative to their production, sometimes leaking more gas than is extracted, captured, and sent to market. Making direct measurements of emissions from marginal oil and gas wells in the Appalachian Basin of southeastern Ohio, a research team from University of Cincinnati showed that emissions of both methane and volatile organic compounds followed a skewed distribution, with many wells having zero or low emissions and a few wells responsible for the majority of emissions. Follow-up measurements at five wells indicated high emissions were not episodic. Some wells were emitting all or more of their reported production gas into the atmosphere. The authors surmised that stochastic processes, such as maintenance, may be the main driver of emissions. "This makes marginal wells a disproportionate greenhouse gas emissions source compared to their energy return, and a good target for environmental mitigation."[1498]

- June 22, 2020 – The bonds that states require of companies to cover plugging of orphan oil and gas wells are grossly inadequate, according to an *E&E News* report.[1499] Orphan oil and gas wells are unplugged abandoned wells the owners of which either cannot be located or cannot afford to properly plug them. Abandoned wells have been implicated in ground water contamination and can leak methane, a potent greenhouse gas. The Interstate Oil and Gas Commission identified 57,000 confirmed orphan wells in the United States, up to an additional 750,000 "potential" orphans, and up to 3 million abandoned and idle wells that have an identifiable owner. Further, more recent wells are deeper and are at higher pressures than older ones. The estimated cost of plugging a (fracked) shale well is about $300,000, versus $40,000 to $50,000 for a conventional well. The piece reported on Congress considering using federal stimulus funds to help cover the cost of plugging orphan wells, providing jobs for oil field workers and pollution reduction. The limited number of skilled workers and specialized equipment for is a challenge already experienced in Ohio.

- June 16, 2020 – A *Reuters* review of government data and interviews with scientists, regulators, and United Nations officials estimated that globally there are 29 million

[1497] Eric D. Lebel et al., "Methane Emissions from Abandoned Oil and Gas Wells in California," *Environmental Science & Technology* 54, no. 22 (2020): 14617–26, https://doi.org/10.1021/acs.est.0c05279.
[1498] Deighton et al., "Measurements Show That Marginal Wells Are a Disproportionate Source of Methane Relative to Production."
[1499] Mike Lee, "Should Feds Plug 'Orphan' Wells? States Offer a Warning," *E&E News*, June 22, 2020, https://web.archive.org/web/20200622133846/https://www.eenews.net/stories/1063430105.

abandoned oil and gas wells, leaking about 2.5 million tons of methane yearly.[1500] The wells "pose a serious threat to the climate that researchers and world governments are only starting to understand," according to the review. Groundwater and soil contamination have also been linked to these wells, and, in rare cases, leaking gas has caused explosions. In the United States, the number of abandoned wells increased by over 12 percent since the onset of the fracking boom in 2008. Continued low oil prices putting financial stress on the industry led to a 50 percent in rise bankruptcies in 2019, likely to result in a further increase in abandoned wells. The upfront bonds required of drillers to cover future cleanup and well plugging are markedly inadequate: "the rules are patchwork, with wildly differing requirements, and they seldom leave governments adequately funded," according to the report. Referencing the US Government Accounting Office estimate of $20,000 to $145,000 per abandoned well clean up and plugging, it would cost between $60 billion to $435 billion to clean up all of the United States' abandoned wells.

- June 11, 2020 – The president of the Northwest Landowners Association in North Dakota, Troy Coons, questioned why the state was using $33.1 million from the CARES Act to plug abandoned wells, rather than have the "bad actor" oil and gas companies fulfill their obligations, according to the *Williston Herald.*[1501] There are 358 wells on the state's list for confiscation but the actual number of abandoned wells is likely much higher. 2,161 inactive wells had been identified in North Dakota as of May 2020. Coons believes that plugging will be more expensive than the state estimates, and that if the state does not adjust bonding requirements to cover the actual cost of well decommissioning, the burden will continue to fall on taxpayers and landowners.

- May 5, 2020 – COVID-19 pandemic-related economic impacts on the oil and gas sector could add thousands to the already over three million abandoned oil and gas wells in the United States, reported *E&E News*. If a solvent responsible party cannot be found, the cost of cleanup falls to state or federal taxpayers. States such as Louisiana, New Mexico, Oklahoma, and Wyoming have instituted policies to help stressed oil and gas companies remain solvent. The federal BLM offered guidance to companies on how to suspend leases. An energy finance analyst, however, said that the poor financial shape and structural weakness of the shale industry already create a "'perfect storm' for a cleanup crisis."[1502]

- April 19, 2020 – An audit by the Louisiana Legislative Auditor's office noted a 50 percent increase in orphaned oil and gas wells in the state, and that it would take an estimated 20 years and $128 million to plug the nearly 4,300 wells. "Rock-bottom" oil prices will force more firms out of business, leading to the number of orphaned wells

[1500] Nichola Groom, "Special Report: Millions of Abandoned Oil Wells Are Leaking Methane, a Climate Menace," *Reuters*, June 16, 2020, sec. Commodities News, https://www.reuters.com/article/us-usa-drilling-abandoned-specialreport-idUSKBN23N1NL.
[1501] Renée Jean, "NWLA Blasts North Dakota's Handling of Abandoned Wells in Confiscated Wells Testimony," *Williston Herald*, July 19, 2021, https://www.willistonherald.com/news/farm_and_ranch/nwla-blasts-north-dakotas-handling-of-abandoned-wells-in-confiscated-wells-testimony/article_06b8f7c2-ac25-11ea-b30c-77a8a8a13091.html.
[1502] Heather Richards, "Coronavirus Could Drive 'Mass Abandonment' of Oil Wells," *E&E News*, May 5, 2020, https://web.archive.org/web/20200507051045/https://www.eenews.net/stories/1063049965.

further rising. *Nola.com* reported that only about two-thirds of the state's wells have financial security guarantees, and the actual cost of plugging was significantly higher than these guarantees. The audit recommended that the Louisiana legislature adjust fees to cover plugging costs. *Nola.com* covered some improvements with state regulation since a "scathing" 2014 audit, but serious financial risks to the state persist. Further, only about half of active wells with a major violation had undergone a required reinspection, and the Department of Natural Resources Office of Conservation had not forced companies to plug almost two thirds of those wells beyond a 90-day requirement and not on an extended closure schedule.[1503]

- April 3, 2020 – There are about 200,000 orphaned wells in Pennsylvania, all with the potential to leak oil and gas to the surface, pollute water, and create explosion hazards, according to a Pittsburgh *Post-Gazette* feature.[1504] At the rate and cost at which the state's Department of Environmental Protection (DEP) is sealing old wells, it would take 17,500 years and $6.6 billion to complete. The state requires operators to seal their wells at the end of production but does not require them to demonstrate that they have adequate financial resources. The feature highlighted the story of ARG resources, owner of 1,600 wells, 150 miles of road, and many buildings and tanks in the Allegheny National Forest. The company closed operations in 2019 because of lack of funds, abandoning wells and leaving nine spills unresolved. According to the DEP, ARG had earned enough during its period of profitability to pay for the cleanup: "plugging and restoration costs should not have been insurmountable." Taxpayers should not have been left with the bill, a DEP supervisor said. Rather than pursue lengthy legal proceedings, DEP signed a consent order involving a revenue-sharing arrangement between ARG and a chemical company, AquaPower, to clean brine wastewater and turn it into commercial salt and synthetic gypsum on ARG's property, with a portion of the proceeds dedicated to abandoned well cleanup. The plan is seen as a potential model to pay for abandoned well management, though AquaPower, at the time of publication, was delinquent in its deposits to begin the operation.

- March 6, 2020 – There are nearly 1,000 orphaned oil and gas wells across Los Angeles County, "deserted by their owners and left to the state to clean," determined a "first-of-its-kind analysis of state records" by the *Los Angeles Times* and the Center for Public Integrity.[1505] Los Angeles mandates that oil or gas wells be restarted or shuttered if inactive for one year but has been delinquent in enforcement. The investigation determined that there was only one full time well inspector until recently, and that the city had not consistently employed a full time "petroleum administrator" despite the city code requiring it to do so. Industry and labor groups have challenged the city's authority

[1503] Mark Schleifstein, "Number of 'orphaned' Wells Increased by 50 Percent, Could Cost State Millions: Audit," *The New Orleans Advocate*, April 19, 2020, https://www.nola.com/news/business/article_313d8dd2-7a9d-11ea-b4a4-e7675d1484f7.html.
[1504] Laura Legere and Anya Litvak, "Unplugged: Pennsylvania Faces a New Wave of Abandoned Oil and Gas Wells," *Post-Gazette*, April 3, 2020, https://newsinteractive.post-gazette.com/unplugged-pennsylvania-faces-new-wave-abandoned-oil-gas-wells/.
[1505] Mark Olalde and Ryan Menezes, "Deserted Oil Wells Haunt Los Angeles with Toxic Fumes and Enormous Cleanup Costs," *Los Angeles Times*, March 5, 2020, sec. Climate & Environment, https://www.latimes.com/environment/story/2020-03-05/deserted-oil-wells-los-angeles-toxic-fumes-cleanup-costs.

to enforce cleanup, as community groups press for closure of old wells and residents nearby, often low-income and Latino, have reported nosebleeds, headaches, and nausea. "Eight hundred oil companies have dissolved over the years without scheduling wells for cleanup or paying state fees," according to the California Geologic Energy Management Division, and bond requirements have not been updated in about 60 years and are inadequate, reported the city controller.

- February 26, 2020 – Uncemented sections of well casings provide pathways for methane to flow from intermediate subterranean zones to shallow aquifers, according to a review of EPA investigations by Maryland Department of the Environment and Penn State scientists.[1506] The researchers evaluated EPA investigations in Dimock, Pennsylvania, Parker-Hood County, Texas, Pavilion, Wyoming, and Sugar Run, Pennsylvania and other studies, regarding the impact of methane migration on water resources. They reviewed various potential causes of methane migration identifying uncemented sections of well casings as the most common cause of contamination incidents from active wells. They noted that they were working with "relatively few, detailed, site-specific studies," and that "the actual scope of the problem is difficult to demonstrate, since impacts to water supplies due to migration of fugitive gases are often adjudicated between operators and homeowners involving nondisclosure agreements." The authors noted that less than half of the attempts to address this problem by "squeeze cementing" were successful. They suggested collecting predrilling samples to determine if methane concentrations increase later on, and recommended forensic methods including isotope analysis of gases to accurately determine fugitive gas sources. The studies did not address potential water resource contamination by hydraulic fracking fluids.

- January 23, 2020 – Plugging the approximately 5,540 oil and gas wells that are orphaned or at high risk of becoming orphaned in California would cost the state over $500 million, estimated the California Council on Science and Technology, a nonpartisan, nonprofit organization created by the state's Legislature, in a report requested by the Division of Oil, Gas, and Geothermal Resources.[1507] The report identified another 69,425 economically stressed wells that produce less than five barrels of oil daily and are at risk of becoming orphaned, which would bring the cost to an estimated $5 billion. According to the report, plugging all 107,000 wells in the state would cost more than $9 billion, and there are also wells that are plugged but may need to be replugged. Though legally required to pay for plugging of their wells, the bonds collected by the state from industry only totaled $107 million at the time of the report. The report makes several recommendations to help limit the state's financial and environmental liability. These include investigation of environmental impacts of orphan wells and evaluating potential changes to bonding rules.

[1506] Patrick A. Hammond et al., "Gas Well Integrity and Methane Migration: Evaluation of Published Evidence during Shale-Gas Development in the USA," *Hydrogeology Journal* 28, no. 4 (2020): 1481–1502, https://doi.org/10.1007/s10040-020-02116-y.
[1507] Judson Boomhower et al., "Orphan Wells in California - An Initial Assessment of the State's Potential Liabilities," Press Release (Californai Council of Science and Technology, January 23, 2020), https://ccst.us/wp-content/uploads/CCST-Orphan-Wells-Press-Release.pdf.

- June 13, 2019 – Both plugged and unplugged abandoned oil and gas wells continue to emit methane, and some categories of plugged wells are high emitters. When the social costs of methane pollution were considered, mitigation of abandoned high-emitting wells was cost-effective, according to a Canadian-U.S. research team.[1508] Social costs were defined as air quality, climate, and human/ecosystem impacts. The authors cited estimates of the social cost of methane emissions as $1143 to $4822 per ton. The study evaluated strategies and costs of mitigating methane emissions. The mitigation options reviewed for high emitting abandoned wells included plugging without venting, or alternatively with venting and flaring, or with venting and usage of the emitted gas. Flaring or usage without plugging address methane pollution but not groundwater contamination, a social cost. The researchers found savings were possible for all mitigation strategies when the full social cost of methane was considered. Because state bonding requirements across the U.S. show that most are insufficient to cover the average plugging cost, they recommended the inclusion of methane emission reduction from abandoned wells in climate and energy policies, and "increased government funding at state/provincial and federal levels to manage the growing number of AOG wells in the US, Canada, and abroad."

- December 8, 2019 – There are an estimated 93,000 inactive and orphaned gas and oil wells in Alberta, Canada, and a rising number of these are owned by companies that are under financial stress and which cannot afford to clean them up. "One of the primary barriers to a clear understanding of the problem appears to be the absence of a credible and transparent assessment of cleanup costs," according to a University of Calgary law professor, writing in the *Globe and Mail*.[1509] In Alberta, the Orphan Well Association is responsible for inactive and orphaned wells, and the levy on industry for cleanup is insufficient to cover the average per well cleanup cost of $27,000 to $34,000 that can also run as high as $210,000. The writer recommended "an independent inquiry into the extent of the oil and gas sector's underfunded environmental liabilities," addressing the problem that, in a worst-case scenario, could triple within a generation from its current $80 billion.

- November 7, 2019 – Many shallow wells were drilled off the coast of Santa Barbara County in the early 1900's, later abandoned, and never plugged properly. This history, on through present activity of the oil and gas industry in the region, was the focus of an *E&E* piece.[1510] Adding to natural seeps in the area, oil leaks from legacy wells and oil spills and pipeline ruptures have polluted beaches and four state marine conservation areas. The California State Lands Commission leads the inventory process and has identified 200 "high priority" orphaned offshore wells. The state passed legislation allocating two million dollars yearly for 10 years, "to take inventory of the orphaned wells, plug them

[1508] Mary Kang et al., "Reducing Methane Emissions from Abandoned Oil and Gas Wells: Strategies and Costs," *Energy Policy* 132 (2019): 594–601, https://doi.org/10.1016/j.enpol.2019.05.045.
[1509] Martin Olszynski, "Opinion: Alberta Ignores the Ticking Time-Bomb of Orphaned Oil and Gas Wells at Its Own Peril," *The Globe and Mail*, December 8, 2019, https://www.theglobeandmail.com/opinion/article-alberta-ignores-the-ticking-time-bomb-of-orphaned-oil-and-gas-wells-at/.
[1510] Heather Richards, "Leaking 'Legacy' Oil Wells Pollute Calif. Beaches, Stir Fears," *E&E News*, November 7, 2019, https://web.archive.org/web/20191107180034/https://www.eenews.net/stories/1061482825.

when they are leaking, and clean up jetties and piers." More recent oil and gas industry bankruptcies also threatened to leave wells abandoned. The piece described Exxon nearly walking away from responsibilities for an offshore platform, later agreeing to a cost share with California. The legislated funding is likely to fall far short: in 2018 it cost $1.2 million to plug one offshore well alone. Exxon continues to try to obtain trucking permits in order to continue producing oil offshore in Santa Barbara County.

- November 6, 2019 – Houston Oil and Gas, based in Calgary, Alberta, ceased operations and left an estimated $81.5 million cleanup liability.[1511] It held 1264 wells, 41 facilities, and 251 pipelines. Some of the wells have already been transferred to Alberta's Orphan Well Association, essentially transferring the burden to taxpayers. The Houston Oil and Gas website, however, states that the company will manage its end-of-life liabilities. Other Alberta oil and gas companies have also shut down or are in financial difficulty since oil prices crashed in late 2014.

- October 22, 2019 – The federal Bureau of Land Management (BLM) does not have a good way of tracking the thousands of idle oil and gas wells on federal land. Funding is inadequate to plug those orphan wells which have already been identified. Aside from the cost to taxpayers, the wells pose a risk of groundwater pollution from hydrocarbons. The federal oil and gas program was included on a 2011 U.S. Government Accountability Office (GAO) list of "high risk" programs vulnerable to fraud, abuse, and mismanagement. In 2019 the GAO reported that 84 percent of bonds (the security that industry pays in advance for cleanup liability) for federal oil and gas development were inadequate to cover cleanup costs. *E&E* reported that despite multiple government investigations, federal data is difficult to obtain, and it is states dealing with orphan wells that "sometimes provide a clearer picture of the challenge."[1512] Wyoming, for example, estimated that there are 2,200 wells on federal land in that state that appear to be orphaned. BLM may be making improvements. The article reported that the agency had collected 16 percent of the additional bonding it has deemed needed for end-of-life well cleanup. BLM lacks authority to directly charge oil and gas operators for cleanup.

- October 1, 2019 – The magnitude and duration of barometric pressure changes directly influenced the natural gas emissions from wells, discovered a team of scientists from the University of British Columbia.[1513] At least seven percent of oil and gas wells show some loss of well bore integrity. Natural gas release from leaking oil and gas wells can cause aquifer contamination, explosive conditions, and greenhouse gas emissions. Complex processes are involved in gas migration and emission. High barometric pressure inhibits the release of soil gas, and the opposite occurs with low pressure, determined the study. The most significant effect seemed to occur in areas with deep water tables. The study

[1511] Kyle Bakx, "Calgary-Based Houston Oil & Gas Ceases Operations, Leaving Almost 1,300 Wells Needing Cleanup," *CBC News*, November 6, 2019, https://www.cbc.ca/news/business/houston-calgary-oilpatch-orphan-wells-1.5348828.
[1512] Heather Richards, "Thousands of 'Orphan Wells' Spark Safety, Cleanup Fears," *E&E News*, October 22, 2019, https://web.archive.org/web/20191023203001/https://www.eenews.net/stories/1061342691.
[1513] Olenka N. Forde et al., "Barometric-Pumping Controls Fugitive Gas Emissions from a Vadose Zone Natural Gas Release," *Scientific Reports* 9, no. 1 (2019): 14080, https://doi.org/10.1038/s41598-019-50426-3.

used controlled release of natural gas injected 12 meters below ground level in an attempt to quantify the effect of atmospheric pressure on fugitive gas emissions. The findings of barometric pressure impacts on emissions indicates that "snapshot" measurements of emissions at well pads may not be accurate. Continuous monitoring over longer time periods is therefore required "to accurately detect and quantify fugitive gas emissions at oil and gas sites with a deep water table."

- September 18, 2019 – A GAO report to Congress identified 2,294 oil and gas wells on federal land which had not produced in over ten years and had not been reclaimed, and warned about the risks from insufficient bonds to reclaim these wells.[1514] The investigation found that BLM identified 89 new orphaned wells between July 2017 and April 2019. The average value of oil and gas bonds the BLM held in 2018 was $2122 per well, slightly lower than in 2008, according to the GAO analysis. Bonds are set at their regulatory minimum and the values have not been adjusted in about 60 years. They do not account for well depth, nor the number of wells covered, factors which greatly influence the cost of cleanup. GAO recommendations included providing the BLM with the authority to assess user fees for reclamation costs and establishing a mechanism to obtain those fees from operators. Congress had not done so as of the time of publication. The BLM should also adjust bond levels to cover expected reclamation costs. The BLM continues to collect and analyze data, but its analysis is not expected to be ready until the first quarter of fiscal year 2021.

- September 6, 2019 – *NPR* featured an overview of the orphaned oil and gas well situation nationwide.[1515] Given the one million orphaned oil and gas wells in the United States as estimated by the EPA in 2018, responsibility for which typically falls to the states, markedly inadequate bonding to cover well cleanup is a growing problem. Colorado, Alabama, Ohio, and Pennsylvania have dramatically increased state funds allocated for well cleanup. The backlog of wells, however, is very large, with an estimated 560,000 abandoned wells in Pennsylvania alone. Industry has pushed back on the suggestion that companies pay the full price of plugging before drilling starts.

- August 10, 2019 – In 2016 San Francisco passed a climate-related ordinance requiring that no city-owned property be used for oil production, specifically to address a lease that Chevron held in Kern County on the city's behalf. *Bakersfield.com* provided an update on ongoing negotiations on covering the costs of decommissioning the wells.[1516] The cost of decommissioning the wells is estimated to be between one million and five million dollars, as a best-case scenario. San Francisco wants Chevron to cover the cost of decommissioning the wells. According to the senior real estate project manager for the City and County of San Francisco, "While I can't get into specifics of our negotiations

[1514] U.S. Government Accountability Office, "Oil and Gas: Bureau of Land Management Should Address Risks from Insufficient Bonds to Reclaim Wells," September 18, 2019, https://www.gao.gov/products/gao-19-615.
[1515] Matt Bloom, "Cleaning Up Abandoned Wells Proves Costly To Gas And Oil Producing States," *NPR*, September 6, 2019, sec. Energy, https://www.npr.org/2019/09/06/758284873/cleaning-up-abandoned-wells-proves-costly-to-gas-and-oil-producing-states.
[1516] John Cox, "Well-Plugging Costs Add Wrinkle to San Francisco's Planned Oil Pullout," *The Bakersfield Californian*, August 10, 2019, https://www.bakersfield.com/news/well-plugging-costs-add-wrinkle-to-san-franciscos-planned-oil-pullout/article_9a43b724-bad7-11e9-8ea8-137db2d851d9.html.

with Chevron, we believe our lease assigns decommissioning responsibilities to the tenant, in this case, Chevron."

- July 2, 2019 – Many fossil fuel extraction sites have been abandoned in the Atlantic Canadian Provinces since extraction began in the early 1600s. Multiple pathways can lead to methane emissions from these wells, including improper abandonment practices, compromised well bore integrity, and subsurface fluid migration. This study used multiple sampling methods to measure methane emissions from abandoned coal mine openings in Nova Scotia as well as from a legacy oil field (abandoned prior to 1952, when abandonment protocols were begun).[1517] A small percentage of sites accounted for the majority of methane emissions. Overall, low emission intensity and frequency were documented compared with other studies. Time after abandonment may have played a role. Emissions may have peaked early after abandonment and may have decreased over time.

- June 23, 2019 – 22,000 deserted oil and gas wells have been identified in Kansas, reported the *Hutchinson News*.[1518] Over 19,000 of the abandoned wells are in Eastern Kansas. The Kansas Corporation Commission (KCC) has prioritized 25 percent of those for cleanup, because of their risk for groundwater contamination. The KCC created a fund in 1996 to finance plugging of abandoned wells, financed by the oil industry. According to the article, the KCC and industry are optimistic about the commitment to plug all the wells, but community members and environmental groups, noting that industry has deep political influence on the Kansas legislature and the KCC and project, are far less satisfied with progress and commitment. Further, the KCC does not have the resources to track all owners of idle wells, and there reportedly are not enough contractors willing to bid on plugging.

- May 20, 2019 – Within the nation's largest regional concentration of abandoned oil and gas wells, the estimate of abandoned oil and gas wells in Pennsylvania alone ranges from 200,000 to 750,000, according to *E&E News*.[1519] Those wells are estimated to cause between five and eight percent of the state's human-caused methane emissions, in addition to presenting other risks including explosion hazards and environmental contamination from leaking oil. The piece reviewed the inadequacy of available funds for cleanup by states as well as on public lands. "Most [states] don't have enough funds to clean up the legacy wells left from the oil industry's first century, and most aren't ready to clean up the tens of thousands of wells drilled during the first decades of the shale drilling boom. Pennsylvania, for example, only has enough money to plug a dozen or so each year." Pennsylvania has allocated about $400,000 per year for well plugging, which at the current rate would require 17,500 years to complete the work. Colorado is planning

[1517] James P. Williams et al., "Methane Emissions from Abandoned Coal and Oil and Gas Developments in New Brunswick and Nova Scotia," *Environmental Monitoring and Assessment* 191, no. 8 (2019): 479, https://doi.org/10.1007/s10661-019-7602-1.
[1518] Tim Carpenter, "Kansas Regulators Struggle with Record-High 22K Abandoned Oil, Gas Wells," *The Hutchinson News*, June 23, 2019, https://www.hutchnews.com/news/20190623/kansas-regulators-struggle-with-record-high-22k-abandoned-oil-gas-wells.
[1519] Lee, "Millions of Abandoned Wells Spark Climate, Safety Fears."

to update bonding requirements, and Ohio has voted to increase the amount of oil and gas production taxes the state spends on well plugging. Ohio's tax on energy production, however, is one of the lowest in the country.

- March 11, 2019 – There are roughly 200,000 abandoned oil and gas wells in Pennsylvania left over from more than a century of drilling. Most are not mapped. Alabama-based Diversified Gas & Oil, which now owns about 23,000 gas wells in the state, reached an agreement with the PA DEP to plug 1,400 abandoned wells over the next 15 years—or bring them back into production. The agreement requires the company to submit a $7 million performance bond to cover the costs of plugging. In 2018, the company plugged 41 wells across its entire operating area.[1520]

- March 5, 2019 – There are 30,000 abandoned oil wells in California, with 1,850 in Los Angeles County. The state is currently not required to report to the public on toxic air emissions from these wells before, during, or after they are plugged, even when idle wells are located within densely populated residential communities. The process of capping wells can itself release harmful gases. Legislation has been proposed to remediate this oversight.[1521]

- February 21, 2019 – While preparing to mine over a natural gas storage field in Greene County, Pennsylvania, a coal company discovered dozens of undisclosed abandoned gas wells at the site, according to a report by the *Pittsburgh Post-Gazette.* "Pennsylvania's history of fossil fuel extraction, combined with modern operations harvesting coal, oil and gas at different depths, makes it a particularly thorny place to work underground."[1522]

- January 25, 2019 – Colorado Governor John Hickenlooper signed an executive order to force the "plugging, remediation and reclamation of all medium- and high-priority orphaned wells and orphaned sites." There are roughly 55,000 oil and gas wells in Colorado. At least 260 are orphaned, which means that the well's owner cannot be identified, usually because of bankruptcy. Inactive wells that are orphaned become the responsibility of the state.[1523]

[1520] Laura Legere and Anya Litvak, "Pa. Strikes Well-Plugging Deal with Largest Conventional Oil and Gas Operator in Appalachia," *Pittsburgh Post-Gazette*, March 11, 2019, https://www.post-gazette.com/business/powersource/2019/03/11/Diversified-Gas-and-Oil-abandoned-wells-plugging-settlement-Pennsylvania-DEP/stories/201903080130.

[1521] Steve Scauzillo, "What Toxins Are Being Emitted from LA County's Abandoned Oil Wells? A Lawmaker Wants to Find Out," *San Gabriel Valley Tribune*, March 5, 2019, https://www.sgvtribune.com/2021/09/01/bill-that-would-eliminate-blood-slave-donor-dogs-in-california-on-way-to-governors-desk/.

[1522] Laura Legere, "Pa. DEP Threatened to Shut down a Gas Storage Field, Fearing Risks to Approaching Coal Mine," *Pittsburgh Post-Gazette*, February 21, 2019, https://www.post-gazette.com/business/powersource/2019/02/21/coal-mine-natural-gas-storage-abandoned-wells-Pennsylvania-Equitrans-Consol/stories/201902200130.

[1523] Anna Staver, "Hickenlooper Signs Order to Release the Locations of Orphan Wells, Sets Deadline to Cap Them," *The Denver Post*, July 18, 2018, https://www.denverpost.com/2018/07/18/hickenlooper-executive-order-orphan-wells/.

- December 21, 2018 – Most fracking operations take place in oil and gas fields with a long history of conventional drilling and therefore with many abandoned wells. The possibility of hydraulic fractures intercepting these old wells and opening a pathway for rapid vertical transport for fluids to the surface or to groundwater aquifers depends on multiple variables. A University of Goettingen-led team used modeling to explore the relevant factors that predict long-term flow and transport of fracking fluids into groundwater aquifers through a leaky, abandoned well. The results showed that wellbore integrity of the abandoned well and its distance from the fracking operation are the two most influential parameters determining the vertical transport of fracking fluid through an abandoned well. The most probable pathway of contaminant transport takes place outside the well casing. Hydraulic fracking fluid tends to spread laterally when sediment layers are permeable, decreasing upward movement of fluid and decreasing contamination distribution in the aquifer. When freshwater aquifers are shallow, the short-term probability of contamination is negligible even in the presence of a leaky, abandoned well. "Model results show that hydraulic fracturing fluid reaches the aquifer three years after production."[1524]

- December 15, 2018 – A University of Vermont-led team explored the ability of various predictive models to forecast fluid migration from and through abandoned wells in Alberta, Canada. Although all the models "performed better than random guessing," none of them perfectly predicted which wells would leak in part because of incomplete data. In Alberta, wells that do not leak at the time they are drilled are not retested until they are abandoned. Continuous monitoring of wells in a small area would allow the models to be retrained with more accurate information. Consistent with previous findings, the models did show that the most important features in predicting whether an abandoned well will leak is the deviation of the well from vertical and the year the well was constructed.[1525]

- November 20, 2018 – An investigation by WPXI, an NBC-affiliated television station in Pittsburgh, reported that Pennsylvania lacks funds to locate, plug, and remediate all potentially dangerous abandoned wells in the state. "Overall the problems could cost the state close to $4 billion, so it is responding to the most critical cases first."[1526]

- November 20, 2018 – There are an estimated 12,000 abandoned wells in West Virginia, of which 4,000 are orphaned and have no owners, according to a story in the *Charleston Gazette-Mail* that reported how gas companies are saving money by leaving depleted wells behind instead of plugging them.[1527]

[1524] Reza Taherdangkoo et al., "Modeling Fate and Transport of Hydraulic Fracturing Fluid in the Presence of Abandoned Wells," *Journal of Contaminant Hydrology* 221 (2019): 58–68, https://doi.org/10.1016/j.jconhyd.2018.12.003.
[1525] James A. Montague, George F. Pinder, and Theresa L. Watson, "Predicting Gas Migration through Existing Oil and Gas Wells," *Environmental Geosciences* 25, no. 4 (2018): 121–32, https://doi.org/10.1306/eg.01241817008.
[1526] WPXI, "Abandoned Oil Wells Hidden under Thousands of Local Properties," November 20, 2018, https://www.wpxi.com/news/top-stories/abandoned-oil-wells-hidden-under-thousands-of-local-properties/875732284/.
[1527] Kate Mishkin, "Drilling Companies Avoiding Responsibility to Plug Orphan Wells, Group Says," *Charleston Gazette-Mail*, November 20, 2018, https://www.wvgazettemail.com/news/drilling-companies-avoiding-responsibility-to-plug-orphan-wells-group-says/article_c423997f-d011-5e8a-a54f-13e54d3c0985.html.

- September 5, 2018 – An investigation of abandoned wells on Native American lands in the San Juan Basin found that the Bureau of Land Management (BLM), responsible for monitoring oil and gas wells on most tribal lands, has routinely failed to require operators to file paperwork on abandoned wells, lacks a clear strategy for identifying them, and does not prioritize cleaning up or remediating them.[1528]

- May 16, 2018 – The GAO reported to Congress that BLM needs to improve its oversight of abandoned oil and gas wells. Companies are supposed to provide bonds up front to cover the costs of plugging abandoned wells and reclaiming the sites, but if they don't, or if the costs exceed expectations, BLM can be liable and taxpayers can shoulder the clean-up costs. "Reclamation costs and potential liabilities likely increased since 2010, but we couldn't determine how much because BLM does not systematically track the data." The GAO recommended that, among other things, the director of BLM should systematically track the actual costs that the agency incurs when reclaiming orphaned wells, the number of orphaned and abandoned wells over time, and the information needed to determine the agency's potential liabilities. The BLM concurred with the GAO's recommendations. There are roughly 94,000 oil and gas wells on federal lands overseen by BLM.[1529]

- Dec 26, 2017 – In 1965, a blowout at a gas well in northeastern Netherlands caused the formation of quicksand, which swallowed up an entire drill rig. Eventually, the area was turned into a park. More than 50 years later, a team of researchers discovered that the site is still leaking methane. They found in the groundwater high levels of methane with an isotopic composition that matched that of the gas reservoir. An analysis of groundwater flow conditions showed that this methane is not a remnant of the blowout but the result of ongoing leakage. "Combined, the data reveal the long-term impact that underground gas well blowouts may have on groundwater chemistry, as well as the important role of anaerobic oxidation in controlling the fate of dissolved methane."[1530, 1531]

- June 28, 2017 – *The Tyee* made public the results of an unreleased 2016 report by the Alberta Energy Regulator (AER) showing that 36 of 335 abandoned oil and gas wells that are located close to occupied buildings in urban areas of Alberta are leaking methane. Six abandoned wells were leaking at levels (10,000 ppm) that pose explosion risks and are considered life-threatening. (Natural background level is about 1.9 ppm.) Based on these findings, the report also estimated that 17,000 of 170,000 abandoned wells in rural Alberta were likely also leaking. The author of the unreleased report said in an interview with *The Tyee* that AER, a corporation that functions in part as a regulatory agency, does

[1528] Rebecca Clarren, "Idle Oil, Gas Wells Threaten Indian Tribes While Energy Companies, Regulators Do Little," *Investigate West*, September 5, 2018, https://www.invw.org/2018/09/05/idle-oil-gas-wells-threaten-indian-tribes-while-energy-companies-and-regulators-do-little/.
[1529] U.S. Government Accountability Office, "Oil and Gas Wells: Bureau of Land Management Needs to Improve Its Data and Oversight of Its Potential Liabilities," Report to Congressional Requesters, May 16, 2018.
[1530] Gilian Schout et al., "Impact of an Historic Underground Gas Well Blowout on the Current Methane Chemistry in a Shallow Groundwater System," *Proceedings of the National Academy of Sciences* 115, no. 2 (2018): 296–301, https://doi.org/10.1073/pnas.1711472115.
[1531] Bob Yirka, "Methane Still Leaking from the Ground at Site of Gas Explosion Decades Ago," *Phys.Org*, December 29, 2017, https://phys.org/news/2017-12-methane-leaking-ground-site-gas.html.

not have the capacity to evaluate the potential threat to public health and safety. "The expertise to assess the health risk of abandoned wells really doesn't exist in house."[1532, 1533]

- March 27, 2017 – In an experimental study, Canadian researchers injected methane gas into a shallow sand aquifer over a 72-day period and monitored methane migration for eight months. After 72 days, they found that half of the methane had vented into the atmosphere and half remained in the groundwater, traveling laterally a greater distance than expected and degrading at a rate less than expected. "Our findings demonstrate that even small-volume releases of methane gas can cause extensive and persistent free phase and solute plumes."[1534, 1535]

- December 21, 2016 – The *Texas Tribune* investigated abandoned oil wells in Texas where the Texas Railroad Commission, which is charged with regulating the oil and gas industry, has tracked and mapped 6,628 unplugged, orphaned wells. The commission is struggling with a ballooning inventory of inactive, leaking wells and decreasing clean-up funds to deal with them. The most recent oil boom, involving horizontal drilling with fracking, added to the problem as drillers cut corners in the rush to bring oil to market. "Just drill the well as fast as possible, because they were under such pressure to get cash flow going," according to a geoscientist interviewed for the story who had recently retired as a groundwater advisor for the Railroad Commission.[1536]

- November 14, 2016 – Methane emissions from abandoned wells vary widely, with a few high emitters responsible for a disproportionately large share of the problem. Using new field measurement and data mining techniques, a Stanford University-led team investigated gas leaks at 88 inactive wells in Pennsylvania in an attempt to identify the characteristics of these "super-emitters." Their results showed that unplugged gas wells and wells located in coal areas had the highest methane flow rates. Well plugging does not always reduce methane emission, especially when the wells are vented. In many areas with extensive coal layers, decommissioning requirements for wells included mandatory venting. Using comprehensive databases, the team also estimated the number of abandoned wells in Pennsylvania to be between 470,000 and 750,000, considerably more than previous estimates of 300,000 to 500,000. The research team calculated that, all

[1532] Andrew Nikiforuk, "Energy Industry Legacy: Hundreds of Abandoned Wells Leaking Methane in Alberta Communities," *The Tyee*, June 28, 2017, https://thetyee.ca/News/2017/06/28/Energy-Industry-Legacy/.
[1533] Andrew Nikiforuk, "Alberta Failing on Risk From Leaking Oil and Gas Wells, Says Expert," *The Tyee*, July 4, 2017, https://thetyee.ca/News/2017/07/04/Alberta-Failing-Leaking-Oil-Gas-Wells-Risk/.
[1534] Aaron G. Cahill et al., "Mobility and Persistence of Methane in Groundwater in a Controlled-Release Field Experiment," *Nature Geoscience* 10, no. 4 (2017): 289–94, https://doi.org/10.1038/ngeo2919.
[1535] Andrew Nikiforuk, "Methane Leaks from Energy Wells Affects Groundwater, Travels Great Distances, Study Confirms," *The Tyee*, April 11, 2017, https://thetyee.ca/News/2017/04/11/Methane-Leaks-from-Energy-Wells-Affects-Groundwater/.
[1536] Jim Malewitz, "Abandoned Texas Oil Wells Seen as 'Ticking Time Bombs' of Contamination," *The Texas Tribune*, December 21, 2016, https://www.texastribune.org/2016/12/21/texas-abandoned-oil-wells-seen-ticking-time-bombs-/.

together, Pennsylvania's abandoned wells contribute 5-8 percent of the state's annual greenhouse gas emissions.[1537, 1538]

- June 20, 2016 – Pennsylvania's attorney general began reviewing regulations requiring drillers to document abandoned oil and gas wells within 1,000 feet of a new fracking site. According to a *Bloomberg* investigation, "This puts Pennsylvania among states such as California, Texas, Ohio, Wyoming and Colorado confronting the environmentally catastrophic legacy of booms as fracking and home development expand over former drilling sites. As the number of fracked wells increases, so does the chance they might interact with lost wells." As noted by *Bloomberg,* state databases document only about 10 percent of the nation's 2.6 million abandoned oil and gas wells; the whereabouts of the vast majority are unknown. Current efforts in Pennsylvania to increase documentation on the location and status of inactive wells rely on "citizen scientists" equipped with GPS and methane sniffers, as well as home and farm-owners living on top of abandoned wells. Over a period of three decades, PA DEP has located and plugged only about 3,000 abandoned wells.[1539]

- May 30, 2016 – New developments of houses, schools, and shopping centers are being built over abandoned oil and gas wells, according to a report by Wyoming Public Media. In most states there is no requirement for homeowners to be notified about abandoned wells on their properties, and these wells are not systematically monitored for leaks, nor are their locations well mapped. A builder who worked in the oil and gas industry for decades and suffered cardiac arrest when methane from an abandoned well he was inadvertently working atop exploded, said that there were "no signs" that a well was there.[1540]

- January 26, 2016 – Researchers tested soil methane levels at 102 United Kingdom decommissioned oil and gas wells between 8 and 79 years old. Thirty percent of the wells had methane at the soil surface that was significantly higher than their control samples in nearby fields. Thirty-nine percent of well sites had significantly lower surface soil methane than their respective controls. Researchers suggested several explanations for the latter results, including replaced soils.[1541]

[1537] Mary Kang et al., "Identification and Characterization of High Methane-Emitting Abandoned Oil and Gas Wells," *Proceedings of the National Academy of Sciences* 113, no. 48 (2016): 13636–41, https://doi.org/10.1073/pnas.1605913113.
[1538] Ker Than, "Study of Abandoned Oil and Gas Wells Reveals New Ways of Fixing the Worst Methane Emitters," *Stanford News*, November 14, 2016, sec. Science & Technology, https://news.stanford.edu/2016/11/14/study-abandoned-oil-gas-wells-reveals-new-ways-fixing-worst-methane-emitters/.
[1539] Jennifer Oldham, "In the Birthplace of U.S. Oil, Methane Gas Is Leaking Everywhere," *Bloomberg*, June 20, 2016, https://www.bloomberg.com/news/articles/2016-06-20/in-the-birthplace-of-u-s-oil-methane-gas-is-leaking-everywhere.
[1540] Stephanie Joyce, "Danger Below? New Properties Hide Abandoned Oil And Gas Wells," *Wyoming Public Radio*, May 30, 2016, https://www.northcountrypublicradio.org/news/npr/474100388/danger-below-new-properties-hide-abandoned-oil-and-gas-wells.
[1541] I.M. Boothroyd et al., "Fugitive Emissions of Methane from Abandoned, Decommissioned Oil and Gas Wells," *Science of The Total Environment* 547 (2016): 461–69, https://doi.org/10.1016/j.scitotenv.2015.12.096.

- October 19, 2015 – Abandoned oil and gas wells near fracking sites can be conduits for methane escape that is not currently being measured, according to University of Vermont researchers. Fractures in the surrounding rock may connect to existing unused oil and gas wells in the area during fracking processes, thus providing a pathway for methane to migrate to the surface. The study used a mathematical model based on the large part of southern New York State underlain by the Marcellus Shale, incorporating "the depth of a new fracturing well, the vertical growth of induced fractures, and the depths and locations of existing nearby wells." The researchers concluded the probability that new fracking-induced fractures would connect to a pre-existing well to be .03 percent to 3 percent. Density of nearby abandoned wells was the largest factor, and researchers pointed out the continuing problem of undocumented abandoned wells.[1542] As noted in an accompanying press release, probabilities are likely much higher: "Industry-sponsored information made public since the paper was published vastly increased assumptions about the area impacted by a set of six to eight fracking wells known as a well pad – to two square miles – increasing the probabilities cited in the paper by a factor of 10 or more."[1543]

- July 9, 2015 – As part of an extensive, peer-reviewed assessment of fracking in California, the California Council on Science and Technology identified leakage through failed, inactive wells as a known mechanism for fracking-related water contamination in other states, including Texas and Ohio, and said that it is not known whether abandoned wells in California likewise function as conduits for groundwater contamination and gas leakage. In California, there are more inactive than active wells. Of the state's nearly one-quarter million oil and gas wells, more than half (116,000) have been plugged and abandoned, while another 1,800 inactive wells are "buried" with only an approximate location known. The locations of another 338 old wells are entirely unknown. California also has 110 orphaned wells, that is, abandoned wells with no owners. Most of California's abandoned wells (53 percent) are located in Kern County.[1544]

- May 15, 2015 – *CBC News* reported that falling gas and oil prices have prompted many smaller companies to abandon their operations in Alberta, Canada, leaving the provincial government to close down and dismantle their wells. In the past year alone, the number of orphaned wells in Alberta increased from 162 to 702. At the current rate of work, deconstructing the inventory of wells abandoned just in the past year alone will be a 20-year task.[1545]

- April 27, 2015 – In a peer-reviewed study, researchers with the U.S. Fish and Wildlife Service documented 5,002 wells located on National Wildlife Refuge System units, in addition to 1,339 miles of pipeline. Almost half of the wells were inactive, while one-

[1542] James A. Montague and George F. Pinder, "Potential of Hydraulically Induced Fractures to Communicate with Existing Wellbores," *Water Resources Research* 51, no. 10 (2015): 8303–15, https://doi.org/10.1002/2014WR016771.
[1543] University of Vermont, "Dirty Pipeline: Methane From Fracking Sites Can Flow to Abandoned Wells, New Study Shows," *News Wise*, October 19, 2015, https://www.newswise.com/articles/dirty-pipeline-methane-from-fracking-sites-can-flow-to-abandoned-wells-new-study-shows.
[1544] Stringfellow et al., "Chapter Two: Impacts of Well Stimulation on Water Resources."
[1545] Tracy Johnson, "Alberta Sees Huge Spike in Abandoned Oil and Gas Wells," *CBC News*, May 15, 2015, https://www.cbc.ca/news/canada/calgary/alberta-sees-huge-spike-in-abandoned-oil-and-gas-wells-1.3032434.

third were active and the remainder either plugged and abandoned or with status unknown. Highlighting the impacts of leaks, spills, and routine operation and maintenance on wildlife conservation efforts, the authors called for regular on-site ecological assessments, improved efforts to plug inactive wells and restore inactive well sites, and a "consolidated and robust regulatory framework" to protect the public's interests.[1546]

- March 24, 2015 – Analyzing data from 42 abandoned oil and gas wells in western Pennsylvania, a Princeton and Stanford team documented a wide range of leakage potentials. As a group, gas wells have higher permeability than oil wells. Among gas wells, methane flow rates are positively correlated with permeability. Subterranean temperatures and temperatures, along with well depth, are all variables that can influence leakage potentials of abandoned wells. The leakage potential of wells drilled prior to 1960 is moderate to high, and plugged wells, as well as unplugged wells, can leak. The authors note that cement plugs are imperfect barriers that can develop defects that allow fluids to flow through gaps between the plug and surrounding hole, through pores or fissures within the plug itself, or directly through cracks in the well casing.[1547]

- December 8, 2014 – A Princeton University team found that abandoned oil and gas wells in Pennsylvania, left over from prior decades of conventional drilling, leak significantly more methane than previously thought. Between 300,000 and 500,000 abandoned oil and gas wells are located in Pennsylvania, and many go unchecked and unmonitored for leaks. Nearly three-quarters are unplugged. Based on direct measurements of methane flow from 19 such wells, most of which were a half century old or older, the researchers estimated that the methane leaks from abandoned wells alone could account for between 4 and 7 percent of human-caused methane emissions in the state. Based on these measurements of positive methane flow from decades-old wells, the authors concluded that cumulative emissions from these abandoned wells "may be significantly larger than the cumulative leakage associated with oil and gas production, which has a shorter lifetime of operation." Further, methane flow rates from plugged wells measured in this study were not consistently lower than unplugged wells and indeed were sometimes higher, even though wells are plugged for the precise purpose of limiting the escape of gases. The authors noted that an estimated three million abandoned oil and gas wells are scattered across the United States and likely represent "the second largest potential contribution to total US methane emissions above US Environmental Protection Agency

[1546] Pedro Ramirez and Sherri Baker Mosley, "Oil and Gas Wells and Pipelines on U.S. Wildlife Refuges: Challenges for Managers," ed. Stephen J. Johnson, *PLoS ONE* 10, no. 4 (2015): e0124085, https://doi.org/10.1371/journal.pone.0124085.
[1547] Mary Kang et al., "Effective Permeabilities of Abandoned Oil and Gas Wells: Analysis of Data from Pennsylvania," *Environmental Science & Technology* 49, no. 7 (2015): 4757–64, https://doi.org/10.1021/acs.est.5b00132.

estimates." In the United States, no regulatory requirements for monitoring methane leaks from abandoned wells exist.[1548, 1549]

- December 1, 2013 – An analysis of reports from the NYS DEC found that three-quarters of the state's abandoned oil and gas wells were never plugged. New York State has approximately 48,000 such wells; many of their locations remain unknown.[1550]

- Aug. 4, 2011 – A report from the EPA to Congress in 1987—and discovered by the *New York Times*—concluded that abandoned natural gas wells may have served as a pathway for hydraulic fracturing fluids to migrate underground from a shale gas well to a water well in West Virginia. In noting that the water well was polluted due to hydraulic fracturing and that such contamination was "illustrative" of contamination from oil and natural gas drilling, the report suggested that additional cases of groundwater contamination from hydraulic fracturing may exist.[1551]

- April 4, 2011 – *ProPublica* reported that abandoned wells have caused problems across the nation including contamination of drinking water in Colorado, Kentucky, Michigan, New York, Texas, and other states. *ProPublica* also found that a draft report from the Pennsylvania DEP described a 2008 incident in Pennsylvania in which a person died in an explosion triggered by lighting a candle in a bathroom after natural gas had seeped into a septic system from an abandoned well. The same draft report documented at least two dozen additional cases in which gas leaked from old wells, and three in which gas from new wells migrated into old wells, seeping into water supplies and requiring the evacuation of homes.[1552]

- May 20, 2010 – The British Columbia Oil and Gas Commission issued a safety advisory after hydraulic fracturing caused a large "kick," or unintentional entry of fluid or gas, into a nearby gas well. The commission reported that it knew of 18 incidents in British Columbia and one in Western Alberta in which hydraulic fractures had entered nearby gas wells. "Large kicks resulted in volumes up to 80 cubic meters [about 100 cubic yards] of fluids produced to surface. Invading fluids have included water, carbon dioxide, nitrogen, sand, drilling mud, other stimulation fluids and small amounts of gas." These cases occurred in horizontal wells with a distance between wellbores of up to 2,300 feet. The Commission wrote, "It is recommended that operators cooperate through notifications and monitoring of all drilling and completion operations where fracturing takes place within 1000m [3,280 feet] of well bores existing or currently being drilled."

[1548] Mary Kang et al., "Direct Measurements of Methane Emissions from Abandoned Oil and Gas Wells in Pennsylvania," *Proceedings of the National Academy of Sciences* 111, no. 51 (2014): 18173–77, https://doi.org/10.1073/pnas.1408315111.
[1549] Bobby Magill, "Derelict Oil Wells May Be Major Methane Emitters," *Climate Central*, June 19, 2014, https://www.climatecentral.org/news/abandoned-oil-wells-methane-emissions-17575.
[1550] Ronald E. Bishop, "Historical Analysis of Oil and Gas Well Plugging in New York: Is the Regulatory System Working?," *New Solutions: A Journal of Environmental and Occupational Health Policy* 23, no. 1 (2013): 103–16, https://doi.org/10.2190/NS.23.1.g.
[1551] Urbina, "A Tainted Water Well, and Concern There May Be More."
[1552] Nicholas Kusnetz, "Danger in Honeycomb of Old Wells," *Pittsburgh Post-Gazette*, April 4, 2011, https://www.post-gazette.com/news/nation/2011/04/04/Danger-in-honeycomb-of-old-wells/stories/201104040149.

Such communication between active wells raises the potential that similar communication can occur between active wells and abandoned wells.[1553]

- 2010 – The NYS DEC cautioned that "abandoned wells can leak oil, gas and/or brine; underground leaks may go undiscovered for years. These fluids can contaminate ground and surface water, kill vegetation, and cause public safety and health problems." As the agency reported, "DEC has at least partial records on 40,000 wells, but estimates that over 75,000 oil and gas wells have been drilled in the State since the 1820s. Most of the wells date from before New York established a regulatory program. Many of these old wells were never properly plugged or were plugged using older techniques that were less reliable and long-lasting than modern methods."[1554] The agency published similar comments in 2008 and 2009.

- January 2009 – In a presentation before the Society of Petroleum Engineers, industry consultant Michael C. Vincent reported on evidence that fractures from hydraulically fractured wells can communicate with nearby oil and gas wells. In spite of numerous examples of fractures intersecting with adjacent wellbores, the industry is reluctant to publish reports documenting these cases because "such information could unnecessarily alarm regulators or adjacent leaseholders." Vincent added, "Although computing tools have improved, as an industry we remain incapable of fully describing the complexity of the fracture, reservoir, and fluid flow regimes." These findings raise the possibility that there could be similar communications between existing fracked wells that are fractured and abandoned wells and that operators cannot accurately predict how these will interact.[1555]

- 2005 – M.K. Fisher, Vice President of Business Management at Pinnacle, a service of Halliburton that specializes in hydraulic fracturing, reported in an article published by the Society of Petroleum Engineers that a single fracture produced during a fracking operation in the Texas Barnett Shale had unexpectedly spread 2,500 feet laterally in two directions. He also described fractures in the Barnett Shale as "extremely complex."[1556] These findings raise the possibility that well communication over very large distances could occur due to fractures that spread "unexpectedly."

- October 1999 – The U.S. Department of Energy reported that there were approximately 2.5 million abandoned oil and gas wells in the U.S.[1557]

[1553] British Columbia Oil & Gas Commission, "Safety Advisory: Communication during Fracture Stimulation," Safety Advisory, May 20, 2010, https://www.bcogc.ca/node/5806/download.
[1554] New York State Department of Environmental Conservation, "New York Oil, Gas and Mineral Resources 2010," 2010.
[1555] Mike Vincent, "Examining Our Assumptions – Have Oversimplifications Jeopardized Our Ability to Design Optimal Fracture Treatments?" (Hydraulic Fracturing Technology Conference, Society of Petroleum Engineers, The Woodlands, TX, January 19, 2009), http://www.spe.org/dl/docs/2010/MikeVincent.pdf.
[1556] Marc Kevin Fisher et al., "Integrating Fracture Mapping Technologies To Improve Stimulations in the Barnett Shale," *SPE Production & Facilities* 20, no. 02 (2005): 85–93, https://doi.org/10.2118/77441-PA.
[1557] U.S. Department of Energy, Office of Fossil Energy, "Environmental Benefits of Advanced Oil and Gas Exploration and Production Technology," Technical Report (USDOE Office of Fossil Energy, Washington, DC (US), October 1, 1999), https://doi.org/10.2172/771125.

- Early 1990s – An underground waste disposal well in McKean County, Pennsylvania, contaminated groundwater when the wastewater traveled up a nearby abandoned, unmapped, and unplugged oil well. Owners of private water wells that were contaminated by the incident eventually had to be connected to a public water system.[1558]

- July 1989 – In the past, the investigative agency for Congress, the U.S. General Accounting Office (now the Government Accountability Office—GAO) studied oil and natural gas underground injection disposal wells and found serious cases of contamination. The agency reported that, in several cases, wastewater from oil and natural gas operations had migrated up into abandoned oil and natural gas wells, contaminating underground water supplies. The GAO found that "if these abandoned wells are not properly plugged—that is, sealed off —and have cracked casings, they can serve as pathways for injected brines [waste fluids from natural gas and oil drilling] to enter drinking water…. Because groundwater moves very slowly, any contaminants that enter it will remain concentrated for long periods of time, and cleanup, if it is technically feasible, can be prohibitively costly."[1559]

- December 1987 – The EPA submitted a report to Congress on oil and natural gas wastes in which the agency cautioned that abandoned wells must be plugged with cement in order to avoid "degradation" of ground and surface waters as a result of pressurized brine or injected waste from wastewater disposal wells migrating into to aquifers, rivers, or streams.[1560] While the EPA did not address the potential for contamination through abandoned wells as a result of hydraulic fracturing, both hydraulic fracturing and underground injection disposal wells require underground injection of fluid under pressure, raising the potential that there is a similar risk of groundwater contamination when hydraulic fracturing occurs near abandoned wells.

- 1985 – In an investigation of 4,658 complaints due to oil and natural gas production, the Texas Department of Agriculture found that "when a water well is experiencing an oilfield pollution problem (typically, high chlorides), the pollution source is often difficult to track down. The source could be a leak in the casing of a disposal well, leakage behind the casing due to poor cement bond, old saltwater evaporation pits, or, most often, transport of contaminants through an *improperly plugged abandoned well*" (emphasis in original). The agency found more than a dozen confirmed or suspected cases in which pollutants had migrated up abandoned wells and contaminated

[1558] Don Hopey, "Wastewater Disposal Wells under Scrutiny Following Irvin Leak," *Pittsburgh Post-Gazette*, January 3, 2012, https://www.post-gazette.com/news/environment/2012/01/03/Wastewater-disposal-wells-under-scrutiny-following-Irvin-leak/stories/201201030332.
[1559] U.S. Government Accountability Office, "Drinking Water: Safeguards Are Not Preventing Contamination From Injected Oil and Gas Wastes."
[1560] U.S. Environmental Protection Agency, "Report to Congress: Management of Wastes from the Exploration, Development, and Production of Crude Oil, Natural Gas, and Geothermal Energy," December 1987, https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=20012D4P.pdf.

groundwater. In one case, drilling wastewater migrated up an abandoned well a half mile away from where the wastewater was injected underground for disposal.[1561]

- November 1978 – In a report later cited by the EPA in its 1987 report to Congress (cited above), the state of Illinois Environmental Protection Agency found that oil and natural gas wastes injected underground could migrate through abandoned oil and natural gas wells and contaminate groundwater. The agency wrote, "In old production areas, abandoned wells may pose a serious threat to ground water quality. Unplugged or improperly plugged wells provide possible vertical communication between saline and fresh water aquifers."[1562]

[1561] Texas Department of Agriculture, "Agricultural Land and Water Contamination: From Injection Wells, Disposal Pits, and Abandoned Wells Used in Oil and Gas Production" (Department of Natural Resources, 1985).
[1562] Illinois Environmental Protection Agency, "Illinois Oil Field Brine Disposal Assessment," Staff Report (Water Quality Management Planning, November 1978), http://static.ewg.org/reports/2011/fracking/pdf/ILReport1978.pdf.

Flood risks

Fracking exacerbates flood risks in two ways. First, massive land clearing and forest fragmentation that necessarily accompany well site preparation increase erosion, run-off, and risks for catastrophic flooding. The construction of access roads, easements for pipelines, and build-out of other related infrastructure further contribute to the problem. Compared to an acre of forest or meadow, an acre of land subject to fracking construction activity releases 1,000-2,000 times more sediment during rainstorms. In addition, in some cases, operators choose to site well pads on flood-prone areas in order to have easy access to water for fracking, to abide by setback requirements intended to keep well pads away from inhabited buildings, or to avoid productive agricultural areas.

Second, the vulnerability of fracking sites to flooding increases the known dangers of unconventional gas extraction, heightening the risks of contamination of soils and water supplies, the overflow or breaching of containment ponds, and the escape of chemicals and hazardous materials. Storage tanks on oil and gas sites appear particularly vulnerable to flood-related damage resulting in toxic spills. A 2019 study documented over 600 hazardous chemical releases from gas installations and offshore oil facilities and pipelines triggered by Hurricanes Rita and Katrina. During Hurricane Harvey flooding in Texas in 2017, Eagle Ford operators reported 31 spills at oil and gas wells, storage tanks, and pipelines. A 2021 study found that such flood-related toxic incidents in the greater Houston area are disproportionately higher in impoverished communities. A 2023 study found that coastal California residents living closest to flood-prone oil and gas wells are disproportionately low-income people of color.

Rising sea levels, more powerful hurricanes, and increased storm surges in coastal areas, all consequences of climate change, are expected to represent an increasing threat to oil and gas infrastructure, especially along the Gulf coast. According to a 2018 study, natural gas processing plants in U.S. coastal areas are among the energy infrastructure most vulnerable to inundation by sea level rise. So-called natural hazard-triggered technical disasters, or "natech events" are the focus of a growing area of research.

- May 2, 2023 – A mapping study identified 129 hazardous industrial facilities at high risk for flooding in coastal California by 2050 due to rapidly rising sea levels. Oil and gas wells—along with ancillary fossil fuel infrastructure—made up a large fraction of these sites. The study also found that residents living nearest to flood-prone hazardous sites were disproportionately low-income, elderly, unemployed, and non-white. By the end of the century, the number of at-risk hazardous sites could rise to 423, imperiling even more socially vulnerable communities from flood-induced contaminant releases. "Because we did not include pipelines in our analysis, we underestimated the extent of oil and gas infrastructure that may threaten communities with contaminant releases due to sea level rise. Prior analyses suggest about 90 to 290 km of natural gas pipelines are projected to be flooded by century's end due to sea level rise in the San Francisco Bay Area alone."[1563]

[1563] Cushing et al., "Toxic Tides and Environmental Injustice."

- July 20, 2022 – An analysis of permits and other public records revealed that at least 20 new major oil and gas plants have been proposed in flood zones. These include seven LNG export terminals and six natural gas compressor stations. Five of the proposed projects are located on the Texas Gulf coast where industrial malfunctions and toxic chemical releases to air and water followed Hurricane Harvey's wake in 2017.[1564]

- May 2, 2023 – Spring flooding in April 2023 worsened erosion near the 70-year-old Enbridge Line 5 oil and gas pipeline in northern Wisconsin, heightening fears of exposure among the Bad River Band of Lake Superior Chippewa whose reservation is nearby. Line 5 carries crude oil and natural gas liquids across northern Wisconsin and Michigan to Sarnia, Ontario. Enbridge is planning to relocate the Line 5 pipeline around the Bad River reservation by constructing 41 miles of new pipeline.[1565, 1566]

- April 19, 2021 – The concentration of oil and gas waste facilities, petroleum and natural gas facilities, and petroleum bulk terminals was greatest in the lower socioeconomic status (SES) areas of the greater Houston metropolitan area, and the majority of incidents at toxic sites occurred at petroleum and natural gas facilities, according to the first study addressing disparities in exposure to toxic incidents following Hurricane Harvey in 2017. This Mount Sinai School of Medicine-led analysis demonstrated that low SES areas were more likely to have a toxic release, even after taking into account the greater number of toxic sites in lower SES areas. The actual flooding was highest in the second-lowest quintile of SES and lowest in the highest SES quintile of the study areas. But because flooding was not found to be a significant predictor of an incident at a toxic site related to the hurricane, researchers wrote that this suggests "there are other unmeasured variables that contribute to incidents occurring in lower SES areas," possibly including "lower maintenance or upkeep of facilities, gaps in safety measures, encompassing an overall absence of resiliency to natural disasters." After petroleum and natural gas facilities, other site types with high numbers of incidents were chemical facilities and superfund sites.[1567]

- December 16, 2020 – Of the major storms impacting southeast Texas from 2001 through 2019, Hurricane Harvey had by far the most serious effect on the oil and gas sector, including impacts on employees. Lamar University researchers analyzed industry practices related to resilience and recovery, using a participatory methodology. As expressed by industry representatives, unmet needs included the modernization of flood gauges; availability of high-water vehicles; revised regulations allowing for the use of

[1564] Brendan Gibbons, "At Least 20 Major Oil and Gas Plants Proposed in Flood Zones," *Oil and Gas Watch Newsletter*, July 20, 2022, 20, https://news.oilandgaswatch.org/post/dozens-of-major-new-oil-and-gas-plants-proposed-in-flood-zones.
[1565] Danielle Kaeding, "Spring Flooding Worsens Erosion near Enbridge Pipeline, Heightening Fears of Exposure," WPR.org, May 2, 2023, https://www.wpr.org/wisconsin-spring-flooding-erosion-enbridge-pipeline-bad-river-tribe.
[1566] Wisconsin Department of Natural Resources, "Draft Environmental Impact Statement: Proposed Enbridge Line 5 Relocation Project" (Wisconsin Department of Natural Resources, December 2021), https://widnr.widen.net/s/pmjdl6pbpd/el5_drafteis_dec2021_vol1-deis.
[1567] Wil Lieberman-Cribbin et al., "Socioeconomic Disparities in Incidents at Toxic Sites During Hurricane Harvey," *Journal of Exposure Science & Environmental Epidemiology* 31, no. 3 (2021): 454–60, https://doi.org/10.1038/s41370-021-00324-6.

drones for emergency response; revised labor standards to ease labor shortages following emergencies; and improved logistics and communications, as flooded roadways impeded the ability to receive cargo, including spare parts, from the airport. Rainfall during Harvey exceeded the internal drainage capacity of the oil and gas facilities. At one plant, corrosion of equipment remained unremediated for more than a year after the flood. The study also looked at industry changes made in the aftermath of Harvey. These included the physical raising of facilities and equipment. The study reported that nearly half of oil and gas industry employees were affected personally by the flood, and employees' family safety and damaged homes impeded their return to work. Employees on site at the time of the hurricane could not go home, and lack of food and medication on site were identified as problems. Some companies reported considering purchasing high-water vehicles with 40-inch tires to move personnel in these emergencies.[1568]

- April 29, 2020 – Fracking should be designated an "unacceptable use" of the floodplains of Australia's western Queensland channel country, according to the report of an independent scientific panel commissioned by that state's government that was blocked from public release.[1569] *Guardian Australia* obtained the panel's report which said it "wanted the state to establish a designated wetland and floodplain precinct in which fracking would be banned, and gas wells restricted from frequently flooded areas."

- December 24, 2019 – Hurricane Harvey in 2017 resulted in "extraordinary damage" to onshore industrial facilities, including oil and gas infrastructure, and storage tanks were the most frequently damaged pieces of equipment, according to an investigation using government incident databases documenting accidents involving hazardous chemicals. Researchers found that fully 42 percent of the hurricane-related accidents involved storage tanks, thus adding data and evidence to previous research that had identified storage tanks as highly vulnerable to catastrophic damage from storms and floods. Storage tanks released hundreds of thousands of kilograms of their hazardous contents during Harvey. No plans were in place to deal with the volume of rain that fell during this category 4 hurricane. Calling this an "unforeseen new failure mode," and acknowledging the role of climate change in causing more frequent and more severe disasters, researchers called for review and updating of design standards of floating roof storage tanks. At least 400 storage tanks in the Houston region have this type of roof.[1570]

- November 5, 2019 – Noting that floods will be increasing in frequency and severity due to climate change, researchers studied the impact of flood water on natural gas pipeline transmission valves to identify possible threats to safety and demonstrated that flooding presents risks of corrosion beyond routine threats. The chemical composition of flood

[1568] Gevorg Sargsyan et al., "Analysis of Risk Management Practices of the Oil and Gas Industry in Southeast Texas During Hurricane Harvey," *Journal of Applied Business and Economics* 22, no. 12 (2020), https://doi.org/10.33423/jabe.v22i12.3882.
[1569] Ben Smee, "Scientific Advice Recommending Ban on Fracking in Lake Eyre Basin Kept Secret and Ignored," *The Guardian*, April 29, 2020, sec. Australia news, https://www.theguardian.com/australia-news/2020/apr/29/scientific-advice-recommending-ban-on-fracking-in-lake-eyre-basin-kept-secret-and-ignored.
[1570] Rongshui Qin, Nima Khakzad, and Jiping Zhu, "An Overview of the Impact of Hurricane Harvey on Chemical and Process Facilities in Texas," *International Journal of Disaster Risk Reduction* 45 (2020): 101453, https://doi.org/10.1016/j.ijdrr.2019.101453.

waters, which can vary widely, "had an aggressive effect on the metals." Flood waters may also scour the surrounding land, leading to loss of mechanical stability of gas pipelines, particularly at various parts including valves. Specifically, this study found that the loss of stability of a gas pipeline would be most dangerous for flange connections, due to the additional forces of the underwater environment, and can also be the result of "force moments," which can trigger changes in the load balance. Flange connections comprise some valve connections in aboveground gas pipelines. This study provides additional evidence and detail to previous research demonstrating the long-term negative impact of flood waters on the operation of transmission systems. "[T]here is often a conflict between economic conditions and ensuring the appropriate safety of transmission systems," researchers wrote.[1571]

- August 5, 2019 – The oil and gas industry is "both a victim and a perpetrator" of the landslides and sinkholes linked to the industry's Pennsylvania activity and infrastructure, according to the Pittsburgh *Post-Gazette*.[1572] "With hundreds of well pads and thousands of miles of pipelines newly added to the ground in Pennsylvania over the past decade, the industry's development disturbs the surface and eliminates some trees and vegetation that would otherwise absorb rainfall. Then the rain, in turn, floods culverts, soaks the ground and moves soil without regard for what pipelines may be relying on its support." The article also covered the "precipitation spikes" in the state, noting the twelve months previous to publication were the rainiest on record, with nearly two feet more rain than an average year for the last century. According to an engineering professor quoted in the piece, very few of the industry's infrastructure standards have been updated to account for this climate change impact.

- May 29, 2019 – A George Washington University research team described the "potential disastrous and growing" public health risks that the combination of increasingly extreme weather, chemical facilities, and vulnerable populations presents. They present findings on recent natural hazard-triggered technical disasters, or "natech" events, which are the focus of a growing area of research. Natech events include the "over 600 hazardous material releases from gas installations and offshore oil facilities and pipelines," triggered by Hurricanes Rita and Katrina.[1573] Their own research identified 872 highly hazardous chemical facilities within 50 miles of the hurricane-prone U.S. Gulf Coast, and 4,374,000 people, 1,717 schools, and 98 medical facilities within 1.5 miles of these facilities.

- March 5, 2019 – In the aftermath of Hurricane Harvey, which brought record rainfall and widespread flooding to Houston and Galveston, the state of Texas and the U.S.

[1571] Mariusz Łaciak et al., "Impact of Flood Water on the Technical Condition of Natural Gas Transmission Pipeline Valves," *Journal of Loss Prevention in the Process Industries* 63 (2020): 103998, https://doi.org/10.1016/j.jlp.2019.103998.

[1572] Anya Litvak and Laura Legere, "Too Much Rain Is Messing with Pipeline Operators' Infrastructure Plans | Pittsburgh Post-Gazette," *Pittsburgh Post-Gazette*, August 5, 2019, https://www.post-gazette.com/business/bop/2019/08/05/Too-much-rain-is-messing-with-pipeline-operators-infrastructure-plans/stories/201908040010.

[1573] Susan C. Anenberg and Casey Kalman, "Extreme Weather, Chemical Facilities, and Vulnerable Communities in the U.S. Gulf Coast: A Disastrous Combination," *GeoHealth* 3, no. 5 (2019): 122–26, https://doi.org/10.1029/2019GH000197.

Environmental Protection Agency (EPA) prohibited a National Aeronautics and Space Administration (NASA) plane "equipped with the world's most sophisticated air samplers" to fly over chemical spills, fires, flooded storage tanks, damaged plants, and flooded Superfund sites. Instead, a single-prop plane was used by the EPA to gather information on about two dozen air pollutants, whereas the NASA jet could have analyzed more than 450. At the same time, the Texas governor began a seven-month suspension of state air pollution emissions rules. A subsequent investigation by the Associated Press and the *Houston Chronicle* showed there was "widespread, unreported pollution and environmental damage in the region. The team identified more than 100 storm-related toxic releases, including a cloud of hydrochloric acid that leaked from a damaged pipeline and a gasoline spill from an oil terminal that formed 'a vapor cloud.'"[1574]

- November 30, 2018 – According to the *Miami Herald*, a new Florida Power & Light gas plant, replacing an existing one, will be raised 11.5 feet "to protect from sea level rise, a growing threat caused by emissions from fossil fuel plants." The region is expected to see 14 to 34 inches of sea level rise by 2062. Testimony at a public hearing, following an outpouring of public opposition to the project, included objections to further investments in fossil fuel projects. "What will you tell residents when the last of their personal possessions wash out to sea and the plant that fuels that tide stands above them?"[1575]

- November 29, 2018 – Storm protections will not be coming nearly as quickly as the planned tens of billions of dollars in new natural gas processing and chemical facilities along the Texas gulf, explained a collaborative investigative article in the *Texas Tribune*. "Many of the proposed, under-construction or recently built facilities along the Texas Gulf are in areas that felt [Hurricane] Harvey's bite." Harvey dropped more rain than any storm on U.S. record and led to chemical spills, contaminant releases to the air, and explosions at oil, gas, and chemical facilities. "Extensive storm modeling by top Texas scientists has shown that if a hurricane hit near the southern end of Galveston Island outside Houston… storm surge would pour into the Port of Houston, dislodging thousands of storage tanks full of crude oil and hazardous chemicals."[1576]

- September 14, 2018 – In Beaver County, Pennsylvania, a landslide following heavy rains and flooding caused an explosion of a new section of Energy Transfer Partners' Revolution Pipeline one week after it was operational, according to an investigative piece in *Environmental Health News*. The explosion destroyed a house, other structures, and vehicles, and forced evacuations. A few months earlier, a TransCanada natural gas

[1574] Susanne Rust and Louis Sahagun, "Post-Hurricane Harvey, NASA Tried to Fly a Pollution-Spotting Plane over Houston. The EPA Said No," Los Angeles Times, March 5, 2019, https://www.latimes.com/local/california/la-me-nasa-jet-epa-hurricane-harvey-20190305-story.html.
[1575] Alex Harris and Samantha J. Gross, "FPL to Build New Fossil Fuel Plant — and Elevate It 11 Feet to Protect from Sea Rise," *Miami Herald*, November 30, 2018, https://www.miamiherald.com/news/local/community/broward/article222435610.html?fbclid=IwAR3mbqV7WBYvpGOzmLpbz1R6q1gxZQJzwXQ84fmx0RBocfyaG93M6bsZGws.
[1576] Jamie Smith Hopkins and Kiah Collier, "Surge of Oil and Gas Flowing to Texas Coastline Triggers Building Boom, Tensions," *The Texas Tribune*, November 29, 2018, https://www.texastribune.org/2018/11/29/oil-and-gas-surge-texas-coastline-triggers-building-boom-tensions/.

pipeline in Marshall County, West Virginia exploded due to landslide. In its recent permit application, Shell Pipeline Company identified 25 locations prone to landslides along the route of its proposed Falcon Ethane Pipeline through Pennsylvania, Ohio, and West Virginia.[1577]

- September 11, 2018 – Pipeline construction guidelines are based on standards that do not account for recent changes in weather patterns, and flood risks are particularly exacerbated along the Mountain Valley Pipeline route, which passes through extraordinarily rugged terrain. In a mountainous area of Virginia, pipeline construction workers were compelled to rush preparations for catastrophic rain from Hurricane Florence in summer 2018 as the abnormally wet summer overcame efforts to prevent runoff and erosion.[1578]

- August 22, 2018 –The state of Texas sought at least $12 billion, nearly all of it coming from public funds, to build a nearly 60-mile "spine" of concrete seawalls, earthen barriers, floating gates, and steel levees on the Texas Gulf Coast. This region is home to one of the world's largest concentrations of petrochemical facilities, including most of Texas' 30 refineries. Facilities that would be protected by this project include those owned by the Saudi-controlled Motiva, Chevron, DuPont, and others. Scaled back from earlier proposals, the current one focused on refineries, according to the Associated Press.[1579]

- April 28, 2018 – In their assessment of coastal energy infrastructure at risk along the Gulf Coast, scholars at Louisiana State University concluded that natural gas processing plants in the United States are particularly vulnerable to inundation by sea level rise compared to other energy infrastructure, with up to eight percent of natural gas processing capacity at risk. Tidal flooding is known to be an ancillary effect of sea level rise. Hence, apart from sea level rise itself, "storm surges and flooding from extreme weather-related events often increase the current exposure of these facilities to near-term damage."[1580] Fifteen natural gas processing plants were in the potential inundation zones of the study's various sea level rise scenarios, with nine plants projected to be inundated under all three scenarios.

- December 29, 2017 – Flooding was a central theme in an internationally focused review of energy critical infrastructures at risk from climate change. Potential flood impacts on

[1577] Kristina Marusic, "25 Zones along the Proposed Shell Falcon Pipeline Are at Risk of Explosions Due to Landslides," *Environmental Health News*, September 14, 2018, https://www.ehn.org/here-are-the-25-zones-along-the-proposed-shell-falcon-pipeline-at-risk-of-explosions-due-to-landslides-2604629860.html.
[1578] G. S. Schneider, "Hurricane Could Devastate Virginia Pipeline Project That Is Already Struggling with Changing Weather," *Washington Post*, September 11, 2018, sec. Virginia Politics, https://www.washingtonpost.com/local/virginia-politics/hurricane-could-devastate-virginia-pipeline-project-that-is-already-struggling-with-changing-weather/2018/09/11/572d0ef8-b5cf-11e8-94eb-3bd52dfe917b_story.html.
[1579] Will Weissert, "Big Oil Asks Government to Protect It from Climate Change," *AP News*, April 28, 2021, sec. U.S. News, https://apnews.com/article/us-news-ap-top-news-houston-climate-change-port-arthur-4adc5a2a2e6b45df953ebcba6b63d171.
[1580] David E. Dismukes and Siddhartha Narra, "Sea-Level Rise and Coastal Inundation: A Case Study of the Gulf Coast Energy Infrastructure," *Natural Resources* 09, no. 04 (2018): 150–74, https://doi.org/10.4236/nr.2018.94010.

oil and gas infrastructure take many forms: storm surge flooding damaging aboveground fuel storage tanks; flood-related soil erosion exposing buried underground oil and gas pipelines; and inundation of oil refineries. The authors noted that as climate change "leads to an increase in atmospheric moisture content, the likelihood of extreme precipitation and the risk of flooding increase with associated physical impacts" on infrastructure such as power plants and gas pipelines.[1581]

- September 15, 2017 – Hurricane Harvey and its resulting flooding affected various parts of metropolitan Houston's vast oil and gas operations, as well as the Eagle Ford shale region of South Texas. *Reuters* reviewed company reports to the U.S. Coast Guard on the various releases of petrochemicals around the time of Harvey's hit and subsequent flooding. In addition to more than 22,000 barrels of crude oil, gasoline, diesel, drilling wastewater, and petrochemicals spilled from refineries, storage terminals, and other facilities in the days after the storm, 27 million cubic feet (765,000 cubic meters) of natural gas was released.[1582] Pipeline operators are required to report oil and gas, but not drilling wastewater, spills to the Texas Railroad Commission. An environmental organization retrieved and listed this data, finding 31 spills at oil and gas wells, storage tanks, and pipelines during the hurricane's flooding. The group notes that though the data contains many "produced water" spills, they are likely underreported since they are not mandatory.[1583] More than half the fracking rigs running in the region were estimated to have shut down. "Given that much of oil and gas activity occurs in areas only accessible via dirt roads, the heavy rainfall usually makes the movement of trucks and supplies much more difficult…The trucking and rail of sand, chemicals, and personnel to the well site will all take more time given the likely nasty condition of many Eagle Ford access roads," according to an energy analyst.[1584]

- May 25, 2016 – The removal of photos of flood-related oil spills on a Texas state-run website appears to be an effort to hide visuals that "don't portray the energy business in a flattering light," according to the *El Paso Times* Editorial Board. The photos revealed potential environmental damage caused by flooding at fracking sites.[1585] As earlier reported by the *El Paso Times*, many of the photos shot during Texas' recent floods "show swamped wastewater ponds at fracking sites, presumably allowing wastewater to escape into the environment—and potentially into drinking-water supplies."[1586]

[1581] Cleo Varianou Mikellidou et al., "Energy Critical Infrastructures at Risk from Climate Change: A State of the Art Review," *Safety Science* 110 (2018): 110–20, https://doi.org/10.1016/j.ssci.2017.12.022.
[1582] Emily Flitter and Richard Valdmanis, "Oil and Chemical Spills from Hurricane Harvey Big, but Dwarfed by Katrina," *Reuters*, September 15, 2017, https://www.reuters.com/article/us-storm-harvey-spills/oil-and-chemical-spills-from-hurricane-harvey-big-but-dwarfed-by-katrina-idUSKCN1BQ1E8.
[1583] Environment Texas, "Environmental and Health Concerns About Oil and Gas Spills After Hurricane Harvey," Fact Sheet, September 12, 2017, https://environmenttexas.org/sites/environment/files/reports/Harvey%20Oil%20Gas%20Spills%20-%20Env%20TX%20-%209.22.17.pdf.
[1584] David Wethe, "Harvey's Floods Could Delay 10% of U.S. Fracking: Analyst," *Bloomberg*, August 31, 2017, https://www.bloomberg.com/news/articles/2017-08-31/harvey-s-floods-could-delay-10-percent-of-u-s-fracking-analyst.
[1585] Editorial Board, "Editorial: Hiding Bad News from Texans," *El Paso Times*, May 25, 2018, https://www.elpasotimes.com/story/opinion/editorials/2016/05/25/editorial-hiding-bad-news-texans/84937054/.
[1586] Schladen, "Flooding Sweeps Oil, Chemicals Into Rivers."

- May 1, 2016 – Spring floods across Texas inundated oil wells and fracking sites, tipped over storage tanks, and flushed crude oil and fracking chemicals into rivers, as documented in an Associated Press story that referenced dozens of aerial photographs showing flooded production sites along the Sabine River on the Texas-Louisiana border. (The photographs were later removed from direct public access; see above.) Past president of the American Public Health Association Walter Tsou, MD, called the situation "a potential disaster."[1587]

- June 12, 2015 – At the beginning of 2015, after a month of record-breaking rainfall, Fish and Wildlife Service officials at the Hagerman National Wildlife Refuge in Texas found that floodwaters flowing through oil production well pads in the refuge had inundated dozens of jackpumps, pipelines, and other oil and gas infrastructure, leaving bubbling, oily water and a gassy stench. In 1989, the U.S. Government Accountability Office (GAO) called for "bold action" to address fossil fuel production activities incompatible with the mission of the refuge system. Subsequent reforms have been exceedingly slow, according to a report from *Greenwire*. In most cases, the Fish and Wildlife Service does not know how much fossil fuel is produced or spilled on refuges, and remediation efforts are inadequate. Severe weather events are expected to increase in frequency and severity as climate change progresses, amplifying flood related concerns.[1588]

- June 20, 2014 – The *Coloradoan* reported that Noble Energy storage tanks damaged by spring flooding in Colorado dumped 7,500 gallons of crude oil, fracking chemicals, and fracking wastewater into the Cache la Poudre River, which is both a National Heritage area and a habitat for Colorado's only self-sustaining population of wild trout. Recent high river flows had undercut the bank where the oil tank was located, which caused the tank to drop and break a valve.[1589]

- March 2014 – An extraordinary flood that struck the Front Range of Colorado killed ten people, forced the evacuation of 18,000 more, destroyed more than 1,850 homes, and damaged roads, bridges, and farmland throughout the state. More than 2,650 oil and gas wells and associated facilities were also affected, with 1,614 wells lying directly within the flood impact zone. Many of these storm-damaged facilities and storage tanks leaked uncontrollably. In a later accounting, Matt Lepore, Director of the Colorado Oil and Gas Conservation Commission, estimated the flooding had resulted in the release to the environment of 48,250 gallons of oil or condensate and 43,479 gallons of fracking wastewater from 50 different spill sites across the state. In Colorado, more than 20,850 oil and gas wells lie within 500 feet of a river, stream, or other drainage. According to Director Lepore, setback requirements that keep drilling and fracking operations away

[1587] Chris Siron, "Texas Floods Washing Fracking Chemicals, Crude Oil into Rivers," *The Dallas Morning News*, May 1, 2016, sec. News, https://www.dallasnews.com/news/2016/05/01/texas-floods-washing-fracking-chemicals-crude-oil-into-rivers/.
[1588] Corbin Hiar, "Wildlife Refuges: Floods Expose Weakness in FWS's Oil and Gas Oversight," *E&E News*, June 12, 2015, https://web.archive.org/web/20150617000047/http://www.eenews.net/stories/1060020169.
[1589] Ryan Maye Handy, "Crude Oil Spills into Poudre near Windsor," *The Coloradoan*, June 20, 2014, https://www.coloradoan.com/story/news/local/2014/06/20/crude-oil-spills-poudre-near-windsor/11161379/.

from residential areas inadvertently encourage operators to drill in unoccupied floodplains. At the same time, oil and gas operators prefer locations close to supplies of water for use in fracking. These twin factors result in a clustering of drilling and fracking operations in low-lying areas prone to catastrophic flooding.[1590]

- 2004-2013 – In 2004, 2005, 2006, 2009, 2011, and 2013, several counties targeted for shale gas drilling in New York State experienced serious flooding. These include the counties of Albany, Broome, Cattaraugus, Chautauqua, Chenango, Delaware, Erie, Greene, Madison, Orange, Otsego, Schoharie, Sullivan and Ulster. In 2004, 2005, 2006, 2009 and 2011, floods exceeded 100-year levels in at least some of the counties.[1591, 1592, 1593, 1594, 1595, 1596, 1597]

- February 7, 2013 – In its 2012 annual report to investors, oil and gas drilling company Noble Energy stated, "Our operations are subject to hazards and risks inherent in the drilling, production and transportation of crude oil and natural gas, including … flooding which could affect our operations in low-lying areas such as the Marcellus Shale."[1598]

- September 7, 2011 – The New York State Department of Environmental Conservation's (NYS DEC) draft shale gas drilling plan recommended that drilling be prohibited within 100-year floodplains but acknowledged that many areas in the Delaware and Susquehanna River basins that were affected by flooding in 2004 and 2006 were located outside of officially designated flood zones.[1599] In 2004, 2005, 2006, 2009, and 2011, flooding in New York exceeded 100-year levels in at least some of the counties where drilling and fracking may occur.

[1590] Matt Lepore, "The Colorado Oil and Gas Conservation Commission and the Floods of September 2013—The Response So Far" (Colorado Oil & Gas Conservation Commission, May 20, 2014), https://iogcc.ok.gov/sites/g/files/gmc836/f/coloradofloodsv3_20140520.pdf.
[1591] Lloyd T. Brooks, "Flood of September 18-19, 2004 in the Upper Delaware River Basin, New York," USGS Numbered Series, *Flood of September 18-19, 2004 in the Upper Delaware River Basin, New York*, vol. 2005–1166, Open-File Report (Reston, VA: U.S. Geological Survey, 2005), https://doi.org/10.3133/ofr20051166.
[1592] Thomas P. Suro and Gary D. Firda, "Flood of April 2–3, 2005, Neversink River Basin, New York," Open-File Report (U.S. Geological Survey, 2006), https://pubs.usgs.gov/of/2006/1319/.
[1593] Thomas P. Suro, Gary D. Firda, and Carolyn O. Szabo, "Flood of June 26–29, 2006, Mohawk, Delaware and Susquehanna River Basins, New York," Open-File Report (U.S. Geological Survey, 2009), https://pubs.usgs.gov/of/2009/1063/pdf/ofr2009-1063.pdf.
[1594] Carolyn O. Szabo, William F. Coon, and Thomas A. Niziol, "Flash Floods of August 10, 2009, in the Villages of Gowanda and Silver Creek, New York," Scientific Investigations Report (U.S. Geological Survey, 2010).
[1595] L. Szabo, "REMOVE THIS" (United States Geological Survey, 2011).
[1596] Sistina Giordano, "Several Eastern Counties in Central New York under Water after Heavy Flooding," *Syracule Post-Standard*, June 29, 2013, sec. Central NY News, https://www.syracuse.com/news/2013/06/several_eastern_counties_in_ce.html.
[1597] New York State Department of Environmental Conservation, "Supplemental Generic Environmental Impact Statement (SGEIS) on the Oil, Gas and Solution Mining Regulatory Program: Well Permit Issuance for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs," Technical Report (NYSDEC, 2011).
[1598] Noble Energy, "Annual Report (Form 10-K)," February 7, 2013.
[1599] New York State Department of Environmental Conservation, "Supplemental Generic Environmental Impact Statement (SGEIS) on the Oil, Gas and Solution Mining Regulatory Program: Well Permit Issuance for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs," Technical Report (NYSDEC, 2011).

- 1992 – In its Generic Environmental Impact Statement (GEIS) for oil and natural gas drilling, which was predicated on conventional drilling, the NYS DEC raised concerns that storage tanks holding drilling wastewater, spent hydraulic fracturing fluid, or other contaminants could be damaged by flooding and leak. At the time, the GEIS called for at least some of these tanks to be properly secured.[1600] Shale gas extraction via horizontal fracking would require many more storage tanks for fracking fluids and wastewater than conventional drilling operations anticipated in 1992 when the agency estimated that oil and gas wells in the state would each require 20,000-80,000 gallons of fracking fluid.[1601] As of 2011, the agency anticipated that high volume, horizontally fracked shale gas wells in New York State would each require 2.4-7.8 million gallons of fluid—roughly 100 times the 1992 estimate.[1602]

[1600] New York State Department of Environmental Conservation, "Supplemental Generic Environmental Impact Statement (SGEIS) on the Oil, Gas and Solution Mining Regulatory Program: Well Permit Issuance for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs," Technical Report (NYSDEC, 2011).
[1601] New York State Department of Environmental Conservation, "Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program," 1992, http://www.dec.ny.gov/docs/materials_minerals_pdf/dgeisv1ch8.pdf.
[1602] New York State Department of Environmental Conservation, "Supplemental Generic Environmental Impact Statement (SGEIS) on the Oil, Gas and Solution Mining Regulatory Program: Well Permit Issuance for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs," Technical Report (NYSDEC, 2011).

Threats to agriculture, soil quality, and forests

Drilling and fracking operations pose risks to farming, soil, and forests. Pipeline construction compacts and damages agricultural soils in ways that can persist for decades. On average in the United States, each fracking well is associated with a 3.3 acre reduction in crop acreage. This loss of farmland is exacerbated by potentially permanent soil contamination from fracking wastewater spills. Additionally, studies find soil degradation, lower crop yields, and loss of microbial diversity on farmland intentionally irrigated with oil and gas wastewater. Fracking wastewater reused for irrigation and livestock watering in California's San Joaquin Valley may contain at least ten known or suspected chemical carcinogens, as well as over a dozen chemicals with no available toxicological data and many unidentified compounds currently classified as "trade secrets." A 2020 study found elevated levels of sodium and boron in California soils irrigated with wastewater. Agricultural uses of wastewater, as well as flowback water spills, raise questions about direct exposure of affected soils, contamination of food crops via bioabsorption through plant roots, and impacts on livestock due to ingestion. In California, fracking wastewater illegally injected into aquifers threatens crucial irrigation supplies to farmers in a time of severe drought.

Studies and case reports from across the country have highlighted instances of deaths, neurological disorders, aborted pregnancies, and stillbirths in farm animals that have come into contact with wastewater. In Pennsylvania, ingestion of farm water contaminated with fracking chemicals has been linked to dysphagia, an extremely rare birth defect of the neuromuscular control of swallowing, among horses.

Drilling and fracking operations have led to documented harm to forests and natural areas. In forested areas of Pennsylvania, fracking activities have greatly reduced canopy covers and thereby diminished the carbon storage capacity of photosynthesizing forest trees. Throughout Appalachia, as forests and grasslands are fragmented by fracking operations, their surfaces become more impervious, regional biodiversity declines, and sediment and runoff into nearby streams increases. Soil compaction in cleared areas is detrimental to new plant growth and encourages the growth of invasive species. In Ohio, water withdrawals to service fracking operations episodically reduce the flow of small streams in ways that can disrupt downstream aquatic ecosystems and threaten regionally endangered species. Sharp declines in the abundance and diversity of songbirds in Appalachian forest interiors accompany the arrival of fracking development activities even at low levels of forest loss. In Wyoming, fracking operations are disrupting the migratory movements of mule deer in ways that may lead to lower survival and reproductive success.

- May 29, 2023 – Researchers investigating how the construction of three oil and gas pipelines had affected agricultural soils on the western Canadian prairie found persistent signs of damage more than half a century later, as measured by organic carbon levels, soil compaction, pH, salinity, and calcium carbonate abundance. "Residual effects remained.

Neither soil conservation and reclamation practices, nor natural recovery had yet achieved equivalent capability for the target soil group."[1603]

- May 1, 2023 – Using county-level data on active fracking sites and acreage of crops, a research team investigated the impact of drilling and fracking well pads on agricultural land use across multiple shale basins in the United States during 1997-2018. The team found that, on average, each active well was associated with a 3.3 acre reduction in crop acreage, but with large regional differences. In the Great Plains and in Appalachia, fracking operations negatively affected agricultural land use. In the Southwest, where windfall income from mineral rights may have encouraged farmers to expand crop production rather than take retirement, researchers found a positive relationship between the number of active fracking wells and crop acreage.[1604]

- December 7, 2022 – A systematic literature review evaluated the effects of pipeline installation on soils and plants in agricultural and natural ecosystems. Altogether, the studies showed that pipeline installation degrades soil and inhibits plant productivity in ways that persist for many years. A quantitative analysis found that, compared to non-disturbed adjacent areas, the water infiltration and aggregate stability of soils near pipelines decreased while soil compaction increased. Fifteen out of 25 studies documented declines in crop yields (6.2-45.6 percent), and six out of nine studies reported decreased biomass from natural ecosystems.[1605]

- November 8, 2022 – A systematic quantitative review of the social sciences literature regarding the perceived impacts of fracking on natural resources looked at 96 different papers that used survey research techniques. In more than two-thirds of papers, respondents identified perceived risks associated with land use.[1606]

- October 6, 2022 – Using remote sensing data, a research team in Wyoming investigated how well pads disrupted the movements of mule deer within migratory corridors during the spring. They found that deer did not acclimate to the ecological disturbances that accompanied oil and gas development. Even when only a small portion of their migration corridor was industrialized, herds of mule deer altered their movements and lost their ability to freely move across the landscape to forage on the flush of nutritious spring growth within sagebrush communities. The research team predicted that the decoupling

[1603] Ivan Richard Whitson, "Residual Effects of Pipeline Construction on Agricultural Soils of the Canadian Prairie," *Land Degradation & Development*, May 29, 2023, ldr.4767, https://doi.org/10.1002/ldr.4767.
[1604] Yuelu Xu, Levan Elbakidze, and Xiaoli Etienne, "Unconventional Oil and Gas Development and Agricultural Land Use in the United States," *Journal of Agricultural and Resource Economics* 48, no. 2 (2023): 219–36, https://doi.org/10.22004/AG.ECON.320672.
[1605] Theresa Brehm and Steve Culman, "Pipeline Installation Effects on Soils and Plants: A Review and Quantitative Synthesis," *Agrosystems, Geosciences & Environment* 5, no. 4 (January 2022), https://doi.org/10.1002/agg2.20312.
[1606] Gene L. Theodori et al., "A Systematic Quantitative Review of the Perceived Environmental and Natural Resource-Related Impacts of Unconventional Oil and Gas Development," *The Extractive Industries and Society* 12 (December 2022): 101176, https://doi.org/10.1016/j.exis.2022.101176.

of deer migration from the annual spring "green wave" would result in less body fat for the winter, lower survival, and fewer offspring.[1607]

- September 28, 2022 – An Ohio Northern University study found that water withdrawals from fracking operations episodically reduced the flow of smaller streams in the eastern Ohio River basin in ways that could significantly disrupt downstream aquatic ecosystems and threaten regionally endangered species. Using modelled estimates of historic stream flow, the team found that half of all streams had significant flow reductions (10-20 percent) during fracking operations.[1608]

- August 29, 2022 – In the ten-year period between 2007-2017, permits were granted to 21,000 shale gas wells located on 4,240 well pads in the Marcellus Shale region of Pennsylvania, West Virginia, and Ohio. Researchers investigating ecological changes associated with these sites mapped land use and land cover disturbances with a 25-hectare buffer zone (= 61.8 acres) around well pads in this region. Researchers found that forests and grasslands were the most damaged cover types. On average, disturbances caused by fracking operations damaged 6.2 hectares(15.3 acres) in Pennsylvania, 4.7 hectares (11.6 acres) in Ohio, 4.4 hectares (10.9 acres) in West Virginia, and 5.6 hectares (13.8 acres) over the region. As forests and grasslands are fragmented and their surfaces become more impervious, regional biodiversity declines and sediment and runoff into nearby streams increases.[1609]

- April 28, 2023 – A fourth sinkhole developed in Daisetta, Texas above land used for oil and gas wastewater injection. Daisetta sits above a salt dome, which may have dissolved and caused the cave-in.[1610] [See also entry below for March 16, 2018.]

- March 30, 2022 – A Colorado State University-led study found that only restrictions on fracking or a reduction in the number of wells—by, for example, a transition to renewable energy sources—led to protection of both wildlife populations and public health. Other types of mitigations, such as siting fracking wells away from residential areas and into forested areas, simply shift the burden of harm from human to wildlife populations. The researchers recommend an energy justice framework to mitigate the effects of oil and gas extraction, which includes the element of responsibility, whereby humans recognize the intrinsic value of nonhuman life and acknowledge their obligation

[1607] Ellen O. Aikens et al., "Industrial Energy Development Decouples Ungulate Migration from the Green Wave," *Nature Ecology & Evolution*, October 6, 2022, https://doi.org/10.1038/s41559-022-01887-9.
[1608] Brady Harmon et al., "Flow Alterations in Rivers Due to Unconventional Oil and Gas Development in the Ohio River Basin," *Science of The Total Environment* 856 (January 2023): 159126, https://doi.org/10.1016/j.scitotenv.2022.159126.
[1609] Shawn T. Grushecky et al., "Land Cover Change Associated with Unconventional Oil and Gas Development in the Appalachian Region," *Environmental Management*, August 29, 2022, https://doi.org/10.1007/s00267-022-01702-y.
[1610] Shelby Webb, "Sinkholes Are Emerging in Texas. Is Oil and Gas to Blame?," *E&E EnergyWire*, April 28, 2023, https://www.eenews.net/articles/sinkholes-are-emerging-in-texas-is-oil-and-gas-to-blame/.

to minimize environmental degradation."[1611]

- April 14, 2021 – A study in an area of New Mexico with intense and continuous natural gas drilling activities found that elevated sound levels from gas wells and associated compressor stations impeded the growth and maturation of juniper and pinion pine seedlings. This study also found that noise directly altered the community of seed-dispersing animals upon which both tree species depend for reproduction, resulting in a decline in these foundational species. "We found support for long-term negative effects of noise on tree seedling recruitment, evenness of wood plants and increasingly dissimilar vegetation communities with differences in noise levels…Our results add to the limited evidence that noise has cascading ecological effects."[1612]

- April 9, 2021 – Before proceeding with production-scale fracking, South Africa can learn important lessons about surface impacts to rural and natural areas from the experience of fracking in North Dakota's agricultural Bakken region, according to a South African and North Dakota-based research team. The researchers noted that "energy sprawl" is the largest driver of land-use change in the United States, and that South Africa is unprepared to deal with these impacts. The research was based on the apt comparison of the Bakken to eastern South Africa: the mix of dryland farming and cattle ranching, rural towns, areas of Native lands, and federal conservation lands. A primary lesson learned in this analysis was the necessity to prioritize environmental integrity from the outset in order to prevent the kind of impacts seen in the Bakken. Researchers wrote that Bakken landowners eventually learned strategies to improve outcomes from the industry's soil and vegetation restoration projects, by, for example, writing into their contracts the imperative to use native grasses rather than exotic and annual species for revegetation. By contrast, however, restoring natural grassland is simply not currently feasible in South Africa because commercial seed harvesting and processing are not available at a volume or scale sufficient to support widespread restoration projects.[1613]

- April 9, 2021 – A study of landcover changes and forest structural changes in the Muskingum River Watershed in Appalachian Ohio found extreme damage to forest ecosystems in two areas—Carroll-Harrison counties and Belmont-Guernsey-Monroe-Noble counties—where intensive drilling and fracking activities took place during a boom that reached its peak in 2014 and slowed down by 2018. The loss of core forest was over 14 percent in regions where fracking operations were most dense and also included pipeline rights-of-way. High-resolution aerial images and other remote sensing techniques revealed that about two-thirds of the core forest was lost during the rising phase of the boom, while one-third occurred during the declining phase. The study

[1611] Nicole C Deziel, Bhavna Shamasunder, and Liba Pejchar, "Synergies and Trade-Offs in Reducing Impacts of Unconventional Oil and Gas Development on Wildlife and Human Health," *BioScience*, March 30, 2022, biac014, https://doi.org/10.1093/biosci/biac014.
[1612] Jennifer N. Phillips, Sarah E. Termondt, and Clinton D. Francis, "Long-Term Noise Pollution Affects Seedling Recruitment and Community Composition, with Negative Effects Persisting After Removal," *Proceedings of the Royal Society B* 288 (2021), https://doi.org/10.1098/rspb.2020.2906.
[1613] Devan Allen McGranahan and Kevin Peter Kirkman, "Be Proactive on Energy Sprawl: South Africa Must Anticipate Surface Impacts of Fracking in Rural Areas," *Resources Policy* 72 (2021), https://doi.org/10.1016/j.resourpol.2021.102081.

documented a range of complex ecological damage, including break-up of the forest canopy; conversion of large continuous forest zones into small, isolated forest zones; irreversible changes in microclimate conditions; and the fragmentation and altered movement of wildlife populations.[1614]

- March 15, 2021 – A journalistic investigation found that the pipeline company Cheniere and its construction contractors have trucked away valuable topsoil from Oklahoma farms, flooded fields, and left construction debris and unrepaired swaths cut through soil. Cheniere cited an economic downturn, cost overruns, and the pandemic as reasons for the lack of reconstruction of the farmers' lands.[1615]

- March 12, 2021 – A proposed 12-mile natural gas pipeline to be built by Louisville Electric and Gas (LG&E) will cut through Kentucky's Bernheim Research Forest and Arboretum's Cedar Grove wildlife corridor, which includes habitat for endangered species, including Kentucky glade cress, which grows nowhere else in the world. A media investigation revealed that Beam Suntory, the parent company of Jim Beam Bourbon, would be the sole recipient of the gas for the first five years.[1616]

- March 8, 2021 – Fracking harms natural landscapes in ways that are not limited to its infrastructure footprint alone. An Arkansas-based research team estimated restoration costs on land currently occupied by 400,000 restoration-eligible, non-producing well sites. These sites are largely located on temperate deciduous forest, grassland and pasture, and agricultural lands. The team then also calculated the economic benefits of restoration, including carbon sequestration and agricultural sales. The results showed that the value of carbon sequestration and agricultural benefits from the restoration, accrued over 50 years, was $21.3 billion in 2018 dollars. By contrast, the cost of restoration was $6.9 billion. Thus, the benefit-cost ratio of restoration exceeds 3:1. While the restoration of all abandoned fossil fuel lands in the United States showed economic benefits in this study, the restoration of deciduous forests, grasslands, and Mediterranean ecoregions had the biggest value.[1617]

- February 23, 2021 – Fracking in the Permian Basin of west Texas and New Mexico takes place in arid and semi-arid landscapes. A study that evaluated 1300 cross-sectional parcels of land in this region using high-resolution remote sensing research found significant harm to shrubland and grassland/pasture, with damage to shrubland most pronounced. The impacts were more strongly associated with the shale oil and gas production volume than with the number of wells drilled. The results showed that fracking activities affect vegetation cover in two ways: direct land-use change by clearing vegetation and, secondarily, from spillover impacts on nearby vegetation, as when

[1614] Yang Liu, "Remote Sensing of Forest Structural Changes Due to the Recent Boom of Unconventional Shale Gas Extraction Activities in Appalachian Ohio," *Remote Sensing* 13, no. 8 (2021), https://doi.org/10.3390/rs13081453.
[1615] Mike Soraghan, "Angry Okla. Farmers Fight Pipeline Builder — and FERC," *E&E News*, March 15, 2021, https://web.archive.org/web/20210315220815/https://www.eenews.net/stories/1063727417.
[1616] Ryan Van Velzer, "LG&E Records Show Bernheim Pipeline Would Primarily Benefit Jim Beam," 89.3 WFPL, March 12, 2021, https://wfpl.org/lge-records-show-bernheim-pipeline-would-primarily-benefit-jim-beam/.
[1617] William Haden Chomposy et al., "Ecosystem Services Benefits from the Restoration of Non-Producing US Oil and Gas Lands," *Nature Sustainability* 4 (2021): 547–54, https://doi.org/10.1038/s41893-021-00689-4.

fracking waste creates surface salt formation. These secondary impacts are more difficult to determine and take more time to assess.[1618]

- February 1, 2021 – Benzene from a pipeline leak contaminated soil over four acres and at 20-foot depths on a farm in western Weld County, Colorado. Landowners Julie and Mark Nygren were ultimately forced to remove the soil and demolish their house after discovering that liquid hydrocarbons had pooled beneath it. In April 2019, after years of observing trees dying off on their property, they found green liquid floating in a ditch 130 feet from their house in a discovery that led to a determination that an underground "gathering line" had breached below their farm. As described by Julie Nygren, the resulting clean-up has created ongoing upheaval on their farm including the challenge of "planning to maneuver around the heavy equipment and the trucks that haul as many as 100 loads of contaminated soil to a landfill each day."[1619]

- January 22, 2021 – From 2012 to 2017, the core forest in the karst region of southwestern China decreased by 5.7 percent due to drilling and fracking activities, as determined by high-resolution, remote-sensing images. Though shale gas development was not the main driver of deforestation in this region, which has been experiencing other kinds of development as well, its impact will likely accelerate as shale gas industry development ramps up. Of all the various shale gas activities studied, pipeline construction had the greatest impact on core forest landscape.[1620]

- January 15, 2021 – In a study of North Dakota's four core shale-producing counties and two peripheral counties, researchers using GIS technology found that the footprints of both single wells and multi-well pads were significantly higher than industry estimates. The average single-well pad required 5.26 acres, while the average multi-well pad footprint was 8.60 acres. In the six counties, 23,077 acres of farmland were lost when they were converted by the fracking industry to 3,577 well pads plus access roads that service them. Authors estimated that 22.57 farms were lost with the six affected counties, with an estimated income loss of $4.45 million per year. In addition to farmland, 440 wetlands and 154.68 acres of native woodlands were impacted by well pads and access roads.[1621]

- December 29, 2020 – In some states, fracking wastewater is re-used to irrigate food crops. To determine if the plants can absorb some of the chemicals known to be present

[1618] Haoying Wang, "The Impact of Shale Oil and Gas Development on Rangelands in the Permian Basin Region: An Assessment Using High-Resolution Remote Sensing Data," *Remote Sensing* 13, no. 4 (2021), https://doi.org/10.3390/rs13040824.
[1619] Judith Kohler, "Natural Gas Pipeline Leak Spurs Landowners to Assail Colorado's 'Subterranean Toxic Spaghetti,'" *The Denver Post*, February 1, 2021, https://www.denverpost.com/2021/02/01/colorado-farmers-oil-gas-pipeline-leak-dcp-lawsuit/.
[1620] Yu Guo et al., "Influence of Shale Gas Development on Core Forests in the Subtropical Karst Region in Southwestern China," *Science of the Total Environment* 771 (2021), https://doi.org/10.1016/j.scitotenv.2021.145287.
[1621] Felix N. Fernando and Jon A. Stika, "Exploration of Unconventional Oil and Gas (UOAG) Development on Farmland: Findings from the Bakken Shale of North Dakota," *Extractive Industries and Society* 8, no. 1 (2021): 400–412, https://doi.org/10.1016/j.exis.2021.01.001.

in the waste stream, researchers irrigated wheat with four fracking chemicals known to be linked to health risks, in a greenhouse experiment. They found significant uptake into both the wheat grain and stems for two of the chemicals, diethanolamine and tetramethylammonium chloride (TMAC), compared to the control plants. They found the third chemical, acrylamide, in statistically higher concentrations in the stems only, while didecyldimethylammonium chloride, the fourth chemical, was not detected in grain or stems. To reflect a worst-case scenario situation, researchers used in their experiment the maximum concentrations of the fracking fluid chemicals as reported in the FracFocus database. Results indicated that consuming the wheat with study levels of TMAC, a biocide, would present elevated health risks in both adults and children. Researchers acknowledged that their experimental design did not represent the true chemical complexity of fracking fluids that might potentially be used for agricultural irrigation. They recommended evaluation of more complex chemical mixtures, at various levels, on other plant species. They noted that the expense and resources needed for the research to address the data gaps are significant.[1622]

- June 26, 2020 – "Landscape alteration" is likely to increase by approximately 42 percent under a "low-impact" oil and gas development scenario and by as much as about 299 percent under a "high-impact" scenario, in the Permian Basin of Texas and New Mexico.[1623] Researchers determined through these low-, medium-, and high-impact scenarios that, under each respectively, 60,000, 180,000, and 430,000 new well pads could be constructed through 2050. The Chihuahuan Desert, the largest portion of the study area, was determined to have the largest area of alterations, approximately 70, 200, and 500 percent under the three scenarios. The study's projections only include well pad development, not infrastructure, such as pipelines, compressor stations, and new roads, and authors cited research documenting these developments "can double the amount of alteration caused by well pads alone."

- June 4, 2020 – If reclamation took place on Arkansas lands with abandoned Fayetteville Shale oil and gas infrastructure, researchers estimated a gain of over $2 million annually in agricultural, timber, and carbon sequestration benefits, with benefits far outweighing the costs. The study used an ecosystem services approach, measuring changes using a monetary calculation of the value of natural resources beneficial to humans. Restoring lands to their original habitat, the researchers wrote, would have profound benefits to species requiring contiguous habitat as well as providing an important carbon sink. Almost 20 percent of wells in the Fayetteville Shale are currently non-producing, and as of 2017 only about 20 percent of those had been reclaimed. Nearly all wells in the Fayetteville Shale will be abandoned by 2050, according to the researchers. As the number of active wells declines, the cumulative costs would continue to increase while any oil and gas economic benefits decrease. The study suggested that there would be a two- to four-year break-even period after which regained ecosystem services benefits following reclamation would offset the reclamation costs. The researchers appealed for

[1622] Linsey Shariq et al., "Irrigation of Wheat with Select Hydraulic Fracturing Chemicals: Evaluating Plant Uptake and Growth Impacts," *Environmental Pollution* 273 (2021), https://doi.org/10.1016/j.envpol.2020.116402.
[1623] Jon Paul Pierre et al., "Projected Landscape Impacts from Oil and Gas Development Scenarios in the Permian Basin, USA," *Environmental Management* 66, no. 3 (2020): 348–63, https://doi.org/10.1007/s00267-020-01308-2.

public education to understand the benefits and to support reclamation, with agricultural benefits an "especially efficacious as a way to communicate to the Arkansas public," as the public "might be especially receptive to programs that improve agricultural output, and subsequently the value of private property." Public support of policy changes would be necessary since the state's bonding requirements are inadequate.[1624]

- May 12, 2020 – Soil irrigated by "oilfield produced water" (OPW) in Kern County, California had systematically higher boron and sodium levels than soil irrigated by groundwater, in a study by a team of California and North Carolina researchers.[1625] Researchers concluded that long-term utilization of this blend of oilfield wastewater and surface water could induce boron and sodium toxicity and threaten crops in the long term. The study focused on inorganic chemistry and naturally occurring radioactive materials (NORM), "aiming to evaluate the long-term impact from irrigation with blended OPW as compared to local groundwater." Results indicated that the blended OPW was of comparable quality to the groundwater, with constituents measured below drinking water and irrigation standards. But the findings of elevated boron and sodium, the researchers concluded, pose "long-term risks to soil sodification [excess sodium], groundwater salinization, and plant health." The continued use of OPW for irrigation will require planting of boron-tolerant crops to avoid boron toxicity.

- May 5, 2020 – Research performed by a team from three veterinary research centers found a link between farm water contaminated with fracking chemicals and dysphagia, an extremely rare birth defect involving the neuromuscular control of swallowing, in horses.[1626] Dysphagic foals have difficulty suckling effectively. In 2014, veterinarians at the Cornell University Hospital for Animals found five out of ten foals born on one farm in Pennsylvania (PA) carried this defect. The research team that responded analyzed dysphagia cases in neonatal foals born between 2014 and 2016 on that farm, as well as on an unaffected New York (NY) farm with the same owner, evaluating biological data and environmental exposures on each. The PA farm is located in the northeast region of the Marcellus shale formation and has 28 fracking wells within 10 kilometers. Of the 69 foals born during the study period, 17 were dysphagic and all born in PA, and 48 were normal (11 born in PA, 37 born in NY). Several mares that were on the PA farm for the first half of pregnancy had healthy offspring after being moved to the NY farm mid-pregnancy, and several mares starting off in NY and moving to the PA farm gave birth to dysphagic foals. Both farms used the same feed and hay. The study's environmental analysis found the PA well water to contain higher levels of several polyaromatic hydrocarbons (PAHs) compared to the NY farm water, including 3,6-dimethylphenanthrene, fluoranthene,

[1624] Varenya Nallur, Maureen R. McClung, and Matthew D. Moran, "Potential for Reclamation of Abandoned Gas Wells to Restore Ecosystem Services in the Fayetteville Shale of Arkansas," *Environmental Management* 66 (2020): 180–90, https://doi.org/10.1007/s00267-020-01307-3.
[1625] Andrew J Kondash et al., "The Impact of Using Low-Saline Oilfield Produced Water for Irrigation on Water and Soil Quality in California," *Science of The Total Environment* 733 (2020): 139392, https://doi.org/10.1016/j.scitotenv.2020.139392.
[1626] Kathleen R. Mullen et al., "Environmental Surveillance and Adverse Neonatal Health Outcomes in Foals Born near Unconventional Natural Gas Development Activity," *Science of The Total Environment* 731 (August 2020): 138497, https://doi.org/10.1016/j.scitotenv.2020.138497.

pyrene, and triphenylene. The study's analysis supported nearby fracking activities as the possible contamination source. The installation of a water treatment system reducing the PAHs in the PA water to NY levels eliminated the occurrences of dysphagia. Noting that a "similar study of these environmental variables would be nearly impossible to undertake in humans," the researchers state that "domestic large animals such as horses can serve as important sentinels for human health risks" linked to fracking.

- April 27, 2020 – Forest interior songbird numbers declined "at relatively low levels of overall forest loss" associated with shale gas in Marcellus-Utica shale area landscapes within Pennsylvania, West Virginia, and eastern Ohio, a team of forest and wildlife ecologists determined.[1627] Their study consisted of 2,589 bird surveys at 190 sites across this region over two years. They found that some forest interior species "decreased abruptly in abundance and frequency of occurrence above a threshold of 17.0% overall forest loss." Some more sensitive species similar declined at lower thresholds, from 8.7 to 15.9 percent forest loss. Whereas research has shown that some highly adaptive bird species can increase with human disturbance, this study found that species in these other habitat categories did not increase in landscapes with more than 30.5–36.5 percent forest loss from shale gas development. Researchers concluded that their findings of "declines in abundance and richness of forest interior birds in response to anthropogenic forest disturbance at relatively low levels of forest loss" were consistent with previous findings, and warned that the time period is which shale gas development has taken place in the region would not yet allow for science to have observed "the full range of successional impacts to affected forests, or the full response of species to ongoing changes."

- April 10, 2020 – A case study considered the "misalignment of conservation objectives" by analyzing the effects of fracking in the Bakken shale on North Dakota's Theodore Roosevelt National Park (TRNP).[1628] Authors discussed the potential for conflict between federal oversight of shale oil and gas reserves development with the federal obligation "to preserve designated areas of 'wilderness,' as well as protect social and cultural significance, ecosystem services, recreational benefits, and inherent beauty," with particular attention to the Trump administration's executive orders weakening and repealing pertinent protections. Twelve national parks contain active oil and gas wells within their boundaries, while others, including TRNP, do not, but effects of surrounding oil and gas development have included air pollution, noise pollution, and land fragmentation. Documented "evidence of encroachment" included "noticeable changes to viewscape and soundscape." The authors posit that the Trump administration's steps toward weakening protections and prioritizing oil and gas development over conservation "conflicts with the original intent to set aside TRNP and other federal parklands for current and future generations." They ask, "In regulating fracking and conservation, can the federal government be both the gamekeeper and the poacher?"

[1627] Laura S. Farwell et al., "Threshold Responses of Songbirds to Forest Loss and Fragmentation across the Marcellus-Utica Shale Gas Region of Central Appalachia, USA," *Landscape Ecology* 35, no. 6 (2020): 1353–70, https://doi.org/10.1007/s10980-020-01019-3.
[1628] Miriam R. Aczel and Karen E. Makuch, "Shale Resources, Parks Conservation, and Contested Public Lands in North Dakota's Theodore Roosevelt National Park: Is Fracking Booming?," *Case Studies in the Environment* 4, no. 1 (2020): 1–13, https://doi.org/10.1525/cse.2019.002121.

- March 27, 2020 – West Virginia wildlife researchers found sex-specific genetic changes in Louisiana waterthrush linked to shale gas development, concluding these changes "may affect long-term population survival and fitness" of the species.[1629] This was the first study relating shale gas development to a molecular-level, epigenetic response in a wildlife population. This species is known to be sensitive to changes in ecological conditions and is of conservation concern. It has a specialized habitat and its core breeding range overlaps the Marcellus-Shale region. The researchers' previous six-year study determined that shale gas development negatively impacted the Louisiana waterthrush population. Here, the researchers studied the epigenetic response—DNA changes, or, methylation variation, in response to environmental exposures that may be inherited by future generations—of this species, comparing those in shale gas development regions to those without disturbance from shale gas development. Researchers wrote that their study "adds to existing evidence that methylation varies with pollutant concentrations," and was the first to show a differing pattern of methylation between males and females in a wildlife population. Females had more "methylated restriction sites" than males, which authors proposed may be due to their different use and movement patterns within their territories. Researchers also correlated methylation to the accumulation in feathers of barium and strontium, two heavy metals linked to fracking and already documented to be higher in waterthrush feathers in fracking areas.

- March 14, 2020 – Researchers found degraded soil health, lower wheat yields, and loss of microbial diversity in a greenhouse experiment that involved treating wheat with various dilutions of wastewater from oil and gas production in an effort to determine if it can safely be used as a viable water source for agricultural irrigation. Using a soil health index that reflected chemical, biological, physical, and nutrient properties, the team found irrigation with wastewater from oil and gas production significantly reduced soil health as compared to the soil receiving the control irrigation water. Both dilutions led to lower wheat yields. Further, the microbial community within the soil was significantly different between irrigation treatments in ways that may affect biochemical cycling.[1630]

- November 19, 2019 – Expanding oil and gas well pads and infrastructure covered 2.5 percent and nearly eleven percent of two priority greater sage-grouse population habitat management area zones within the Parachute-Piceance-Roan, according to study by Colorado Parks and Wildlife researchers.[1631] Oil and gas infrastructure developed during the 2005-2015 study period included 195 new well pads, 930 hectares of new pipelines, and 230 kilometers of new roads. The total oil and gas "footprint" within the greater sage-grouse range in this location more than doubled in the study period, with the rate of new energy development slowing from 2009 to 2015. The researchers predicted,

[1629] Mack W. Frantz et al., "Epigenetic Response of Louisiana Waterthrush *Parkesia Motacilla* to Shale Gas Development," *Ibis* 162, no. 4 (2020): 1211–24, https://doi.org/10.1111/ibi.12833.
[1630] Hannah Miller et al., "Reusing Oil and Gas Produced Water for Agricultural Irrigation: Effects on Soil Health and the Soil Microbiome," *Science of the Total Environment* 722 (2020), https://doi.org/10.1016/j.scitotenv.2020.137888.
[1631] Brett L. Walker et al., "Quantifying Habitat Loss and Modification from Recent Expansion of Energy Infrastructure in an Isolated, Peripheral Greater Sage-Grouse Population," *Journal of Environmental Management* 255 (2020): 109819, https://doi.org/10.1016/j.jenvman.2019.109819.

however, that oil and gas will continue to be the main source of greater sage-grouse habitat loss and change in this area over the next few decades. The greater sage-grouse is a "species of concern," that "has experienced historical population declines, especially in peripheral populations" such as the Parachute-Piceance-Roan, and energy development has been widely cited, including by the U.S. Fish and Wildlife Service, as one of the main concerns. This study sought to remedy the "lack the comprehensive, accurate, time-stamped spatial data layers needed to rigorously quantify effects of energy infrastructure" in a greater sage-grouse population. Researchers chose Parachute-Piceance-Roan, which overlays large shale reserves, for its increasing oil and gas development and concern about long-term population viability. Within the study area researchers found that the same topographic constraints that lead to oil and gas development in gentler topography, hold true for the greater sage-grouse habitat preference.

- September 23, 2019 – Farmers in the path of the Spire Inc. STL gas pipeline in Illinois said access to their fields has been blocked, their topsoil damaged, and fields flooded by the construction.[1632] The farmers' claims were backed up by an 80-page inspection report by the Illinois Environmental Protection Agency, linked in the *E&E News* piece, and a consulting firm working on behalf of some of the farmers filed at least 25 complaints with the Federal Energy Regulatory Commission (FERC) on their behalf. Fifty farmers in the pipeline's path had denied easements; the company subsequently employed a legal process called "quick take" to gain access to the properties.

- August 7, 2019 – Between 1975 and 2017, four British Columbian shale gas plays together lost over one percent of their forest cover, due to the construction of well pads, access roads, and pipelines.[1633] The Canadian and U.S. research team combined a geospatial approach with metrics from landscape ecology. Authors suggested that forest cover loss was held to the degree found due to the International Boreal Conservation Science Panel recommendation that "at least fifty percent of the intact boreal forest of Canada should be conserved," but that increased understanding is needed of "specific forest conservation or land management context of each of these shale gas plays."

- June 11, 2019 – Drilling and fracking activities decreased the abundance of forest interior-dependent songbird populations in central Appalachia, according to a study of the relationship between 27 bird species and their distance from shale gas construction in northern West Virginia from 2008 to 2017.[1634] Ovenbird species populations declined 35 percent and cerulean warblers by 34 percent. Over the study period the footprint of shale gas increased tenfold, with a larger increase in new "forest edges." Though other, highly adaptable species may benefit from forest disturbance, the researchers noted that species negatively affected include those of "conservation concern." The researchers stated that

[1632] Mike Soraghan, "'A Muddy Mess.' Ill. Landowners Fight FERC over Pipeline," *E&E News*, September 23, 2019, https://web.archive.org/web/20191226021302/https://www.eenews.net/energywire/stories/1061140891.
[1633] J. Oduro Appiah, C. Opio, and S. Donnelly, "Quantifying, Comparing, and Contrasting Forest Change Pattern from Shale Gas Infrastructure Development in the British Columbia's Shale Gas Plays," *International Journal of Sustainable Development & World Ecology* 27, no. 2 (2020): 114–28, https://doi.org/10.1080/13504509.2019.1649313.
[1634] Farwell et al., "Proximity to Unconventional Shale Gas Infrastructure Alters Breeding Bird Abundance and Distribution."

their findings of losses to populations of edge-avoiding, forest interior bird declines near shale gas development is consistent with other studies of energy development impacts on birds.

- April 9, 2019 – Shale gas development impacted "site fidelity," or breeding site return rates, of the Louisiana waterthrush, according to a six-year study by West Virginia wildlife researchers.[1635] This species is of "conservation concern" because of its specialized habitat, and because most of its core breeding range is within the Marcellus-Utica shale region. Previous research by the team showed diminished waterthrush habitat quality, nest survival, and productivity, and this study turned its focus to site fidelity, typically high among Louisiana waterthrush. This is important, as researchers explained, because "site fidelity can directly influence fecundity and survival of individuals." Specifically, the study analyzed waterthrush annual site fidelity, factors that might affect annual site fidelity, and apparent annual survival across 14 headwater streams with varying amounts of shale gas disturbance in the Lewis Wetzel Wildlife Management Area in West Virginia. Shale gas disturbance on streams varied greatly within each year of the study, but on average streams had more than one-fifth of their length disturbed by fracking development, and there were no undisturbed streams. Results showed that the males had very high site fidelity initially, returning to areas despite lowered habitat quality, but females were less likely to return, had a higher number of breeding attempts, and lowered productivity. The disruptions to the birds' normal behaviors, such as maintaining pair bonds from one year to the next, "may affect the population's long-term persistence," according to the researchers, and their study "adds to previous evidence that shale gas disturbed areas may serve as sink habitats." In sink habitats, death rates exceed birth rates.

- September 15, 2018 – Drilling and fracking operations and their associated infrastructure removed a large volume forest canopy in the upper Susquehanna River basin of New York and Pennsylvania from 2006 to 2013. This loss can be considered permanent, according to U.S. Geological Survey (USGS) scientists. Using "lidar" (light detection and ranging) remote sensing technology, the research team assessed three-dimensional volumetric change of forest loss, as opposed to two-dimensional areal loss. Because trees capture carbon dioxide on the surfaces of their canopy leaves during photosynthesis, three-dimensional measurements allow for the assessment of the carbon storage capacity that is sacrificed to gas development via tree removal. The researchers found that a total of 991,326,760m^3 of forest canopy was removed by oil and gas activities in the upper Susquehanna River watershed area studied. New York's loss was "relatively low" because of the state's fracking moratorium during the study period. The largest losses in forest volumes took place in the Pennsylvania counties of Lycoming, Tioga, Sullivan,

[1635] Mack W. Frantz et al., "Louisiana Waterthrush (Parkesia Motacilla) Survival and Site Fidelity in an Area Undergoing Shale Gas Development," *The Wilson Journal of Ornithology* 131, no. 1 (2019): 84, https://doi.org/10.1676/18-6.

Bradford, Wyoming, and Susquehanna. Although timber operations removed more canopy overall, that loss was concentrated in a smaller area.[1636]

- September 7, 2018 – Cleared areas around fracking well pads in Pennsylvania state forests are subjected to soil compaction equivalent to that in parking lot construction, according to researchers quoted in a *StateImpact* article. Although not used once the well is in production, these cleared areas are not typically repaired or replanted. Further, this level of compaction is detrimental to new plant growth as the soil has fewer pores to store water or gases needed for plant survival. Experimenting with repair for these areas, Penn State University soil scientist Patrick Drohan said, "A lot of our native species, especially the grasses, are very deeply rooted. So if they can get down through 20 inches of loosened soil they're going to be able to develop really deep, nice root systems." Though involved with these experiments and resulting step-by-step repair directions, the Pennsylvania Department of Conservation and Natural Resources is "not proposing to make any of these methods mandatory."[1637]

- July 18, 2018 – A USGS study on the Colorado Plateau investigated vegetation cover at inactive well sites. Researchers found that on half of plugged and abandoned oil and gas well sites, the median vegetation cover after five years was 26 percent, while sites with high vegetation cover were dominated by invasive, non-native species. Using satellite-based Landsat time series analysis, the scientists looked at three to six years of vegetation regrowth at 365 well sites in Utah, Colorado, and New Mexico, drilled in 1985 or after and abandoned in 1997 or after. Vegetation recovery generally slowed over time and was related to moisture conditions year to year. Recovery was lower on abandoned well sites in shrublands or evergreen woodlands, which produced only about half the regrowth of well sites in grasslands. The grassland recovery, however, was dominated by invasive annuals such as cheatgrass and Russian thistle. There are currently over 26,000 abandoned and 63,000 active well pads on the Colorado Plateau.[1638]

- July 17, 2018 – A simulation study that applied actual fracking wastewater to local soils in the Denver area investigated how fracking spills might affect the growth of crops. Spills of fracking wastewater resulted in metal contamination at environmentally relevant concentrations as well as a dramatic decrease in water infiltration rate in ways that could have "severe impact on crop production."[1639] Many of the metals studied, including copper, lead, and iron, "met or approached water quality standards and could have important environmental and human health impacts."

[1636] John Young et al., "Canopy Volume Removal from Oil and Gas Development Activity in the Upper Susquehanna River Basin in Pennsylvania and New York (USA): An Assessment Using Lidar Data," *Journal of Environmental Management* 222 (2018): 66–75, https://doi.org/10.1016/j.jenvman.2018.05.041.
[1637] Reid Frazier, "Bringing the Forest Back after Shale Gas," *State Impact Pennsylvania*, September 7, 2018, https://stateimpact.npr.org/pennsylvania/2018/09/07/bringing-the-forest-back-after-shale-gas/.
[1638] Eric K. Waller et al., "Landsat Time Series Analysis of Fractional Plant Cover Changes on Abandoned Energy Development Sites," *International Journal of Applied Earth Observation and Geoinformation* 73 (2018): 407–19, https://doi.org/10.1016/j.jag.2018.07.008.
[1639] Karl Oetjen et al., "Simulation of a Hydraulic Fracturing Wastewater Surface Spill on Agricultural Soil," *Science of The Total Environment* 645 (2018): 229–34, https://doi.org/10.1016/j.scitotenv.2018.07.043.

- April 13, 2018 – Grasslands and row crop habitats were most affected in a predictive modeling study of vegetation conversion and landscape fragmentation that would result from future drilling and associated well pad construction in the Eagle Ford Shale. The study, which used "energy production outlook" predictions, found that these impacts increased in spatial extent and magnitude as oil prices increased. The study anticipated that up to 83,000 wells would be drilled through the year 2045 and include as many as 45,500 well pads. In this scenario, between 26,485 and 70,623 hectares (65,446 to 174,513 acres) would undergo vegetative conversion. These results are consistent with findings from related studies. The authors cautioned that their model did not include future locations of associated infrastructure, such as surface water impoundments and compressor stations. If they were included, "doubling land-change results of this study… would result in a reasonable estimate of overall footprint of all hydrocarbon extractive infrastructure."[1640]

- July 20, 2017 – Penn State Unversity researchers identified a direct correlation between the spread of invasive, non-native plants in Pennsylvania's northern forests and specific aspects of fracking operations. Researchers surveyed 127 Marcellus Shale gas well pads and adjacent access roads in seven state forest districts in the Allegheny National Forest. The study "found that within less than a decade invasive non-native plants have spread to over half of the 127 well pads in our survey, and for the 85% of the pads that were less than 4 years old it occurred in a much shorter period of time." Gravel shipments and mud on the tires and undercarriages of trucks carry and deposit seeds and propagules of invasive plants. "Given the fact that on average 1235 one-way truck trips delivering fracturing fluid and proppant are required to complete an unconventional well, the potential to transport invasive plant propagules is significant."[1641] "The spread of invasive non-native plants could have long-term negative consequences for the forest ecosystem in a region where the ubiquitous woods provide timbering revenue, wildlife habitat, and ecotourism, warns team member David Mortensen, professor of weed and applied plant ecology."[1642]

- May 15, 2017 – By 2015, the annual ecological cost of fracking in the United States reached over $272 million per year, according to a team of biologists from Hendrix College in Arkansas. They reached this value by estimating the impact of land-use changes on "ecosystem services," the benefits that natural habitats provide to humans, such as carbon sequestration, flood mitigation, food security, ecotourism revenue, and genetic diversity. Authors considered this estimate to be conservative. In addition, they wrote, "[d]epending on future well-drilling rates, cumulative ecosystem services costs projected to the year 2040 range from US$9.4 billion to US$31.9 billion." Their results showed, "that temperate grassland and deciduous forest are being disproportionately

[1640] Brad D. Wolaver et al., "An Improved Approach for Forecasting Ecological Impacts from Future Drilling in Unconventional Shale Oil and Gas Plays," *Environmental Management* 62, no. 2 (2018): 323–33, https://doi.org/10.1007/s00267-018-1042-5.
[1641] Kathryn M. Barlow et al., "Unconventional Gas Development Facilitates Plant Invasions," *Journal of Environmental Management* 202 (2017): 208–16, https://doi.org/10.1016/j.jenvman.2017.07.005.
[1642] Jeff Mulhollem, "Shale Gas Development Spurring Spread of Invasive Plants in Pa. Forests | Penn State University," *Penn State News*, July 20, 2017, https://news.psu.edu/story/475225/2017/07/20/research/shale-gas-development-spurring-spread-invasive-plants-pa-forests.

impacted by unconventional oil and gas development. Temperate grasslands are some of the most imperiled ecosystems in North America." They found "considerable variation in ecosystem services costs between different plays, with Haynesville, Bakken/Three Forks, and Fayetteville showing the highest annual costs."[1643]

- April 2, 2017 – Nearly four percent of "core forest" was lost within six years of shale gas development in Lycoming County, Pennsylvania, from 2010 to 2016. Pipelines were the largest contributor to the industry's spatial footprint and were identified as the major fragmenting feature. "Linear infrastructure" (pipelines and roads) led to 3.2 percent loss of core forest, whereas well pad infrastructure (well pad, water impoundment, compressor station, etc.) resulted in 0.9 percent loss of core forests. "Limiting loss of core forest and fragmentation is of particular importance in Pennsylvania and central Appalachia due to potential impacts to area sensitive species."[1644]

- November 29, 2016 – A study by engineers and environmental scientists from China, the U.K., and the Republic of Korea investigated the impact of contaminated fracking flowback water on soil health, using soils from representative shale gas areas in China. They also performed a preliminary human health risk assessment of exposure to the arsenic found in such soils. The solutions they tested were representative of flowback water from various stages following a fracked well's establishment, and their study found that the temporal change in the composition of these wastewaters "leads to different environmental implications." They tested heavy metal mobility and bioaccessibility, finding that even though mobility was reduced by high ionic strength of flowback water, the metals maintained relatively high bioaccessibility. Soil toxicity moderately increased after a month "aging" with the flowback water treatment. Arsenic, one of the metals included in the testing, is a known human carcinogen and therefore the focus of the human health risk assessment. Results indicated "a low level of cancer risk through exposure via ingestion."[1645]

- October 4, 2016 – A research team from Lawrence Berkeley National Laboratory, University of California Berkeley, and University of the Pacific released preliminary results from a first-ever hazard assessment of chemicals used in California oil drilling operations that reuse wastewater for livestock watering and other agricultural purposes in the San Joaquin Valley. This evaluation, compiled as a technical report by PSE Healthy Energy and Lawrence Berkeley National Laboratory, revealed that more than one-third of the 173 chemicals used are classified as trade secret and their identities are therefore unknown. Of the remainder, ten are classified as either carcinogenic or possibly carcinogenic in humans, 22 are classified by the state of California as toxic air

[1643] Matthew D Moran et al., "Land-Use and Ecosystem Services Costs of Unconventional US Oil and Gas Development," *Frontiers in Ecology and the Environment* 15, no. 5 (2017): 237–42, https://doi.org/10.1002/fee.1492.
[1644] Lillie A. Langlois, Patrick J. Drohan, and Margaret C. Brittingham, "Linear Infrastructure Drives Habitat Conversion and Forest Fragmentation Associated with Marcellus Shale Gas Development in a Forested Landscape," *Journal of Environmental Management* 197 (2017): 167–76, https://doi.org/10.1016/j.jenvman.2017.03.045.
[1645] Season S. Chen et al., "Potential Impact of Flowback Water from Hydraulic Fracturing on Agricultural Soil Quality: Metal/Metalloid Bioaccessibility, Microtox Bioassay, and Enzyme Activities," *Science of The Total Environment* 579 (2017): 1419–26, https://doi.org/10.1016/j.scitotenv.2016.11.141.

contaminants, and 14 had no ecotoxicity or mammalian toxicity data available. "It is difficult or impossible to estimate risks to consumers, farmworkers or the environment," the authors concluded, "when identification of chemical additives remains in trade secret form and/or lacks toxicity and environmental profile information."[1646]

- June 1, 2016 – "Co-contaminant interaction effects" can occur when multiple chemicals are involved in spills of oil and gas wastewater on agricultural soils, according to a study by a Colorado State University research team. Through simulations, researchers analyzed how degradation was affected when combinations of three fracking-related organic chemicals spilled, alone or together: polyethylene glycol, a commonly used surfactant; glutaraldehyde, a biocide to prevent pipe corrosion from microbial activity; and polyacrylamide, a friction reducer. In addition to interactions between the chemicals, they analyzed the role of naturally occurring salts. Results showed that polyethylene glycol surfactants alone can break down in topsoil within 42−71 days, but, in the presence of the biocide glutaraldehyde or salt concentrations typical of fracking wastewater, their biodegradation was impeded or halted altogether. Authors emphasized that the interactions they studied account for only a fraction of the hundreds of fracking chemicals in use, but that their results "show a complex picture of co-contaminant fate and toxicity" that has, so far, been ignored.in the regulatory process.[1647]

- December 12, 2015 – A research team at the University of Aberdeen found high levels of selenium, molybdenum, and arsenic in rock samples collected from a region in northern England that has been targeted for fracking. The finding is important due to the possible risk that these toxic elements will be released into groundwater during shale gas operations. Selenium poisoning has occurred among Irish horses confined to pastures underlain by black shale. While small amounts of selenium are essential for metabolism, high levels (which, in the case of human consumption, is above 400 μg/day) are toxic. Possible consequences include neurotoxicity, cancer and diabetes."[1648]

- November 23, 2015 – Gas-related impacts on Pennsylvania farmers may include pipelines crisscrossing fields and forests, as well as jeopardization of organic certification, according to a report covering a State Agriculture Department spokesman's presentation, on the Potter County government website. The spokesman said, "steps should be taken to steer this development in ways that diminish impact on soil quality and fragmentation." "With trees and other vegetation being cleared from pipeline rights-

[1646] Seth B. C. Shonkoff, William T. Stringfellow, and Jeremy K. Domen, "Hazard Assessment of Chemical Additives Used in Oil Fields That Reuse Produced Water for Agricultural Irrigation, Livestock Watering, and Groundwater Recharge in The San Joaquin Valley of California: Preliminary Results," Technical Report (PSE Healthy Energy, September 2016), https://www.psehealthyenergy.org/wp-content/uploads/2017/04/Preliminary_Results_13267_Disclosures_FINAL-1.pdf.
[1647] Molly C. McLaughlin, Thomas Borch, and Jens Blotevogel, "Spills of Hydraulic Fracturing Chemicals on Agricultural Topsoil: Biodegradation, Sorption, and Co-Contaminant Interactions," *Environmental Science & Technology* 50, no. 11 (2016): 6071–78, https://doi.org/10.1021/acs.est.6b00240.
[1648] John Parnell et al., "Selenium Enrichment in Carboniferous Shales, Britain and Ireland: Problem or Opportunity for Shale Gas Extraction?," *Applied Geochemistry* 66 (2016): 82–87, https://doi.org/10.1016/j.apgeochem.2015.12.008.

of-way, he noted, it's important for the acreage to be replanted with plant species that are beneficial to agriculture—pollinating plants, as an example."[1649]

- October 25, 2015 – More than 180 million gallons of wastewater from oil and gas operations spilled from 2009 to 2014, according to an Associated Press analysis of data from leading oil- and gas-producing states (Texas, North Dakota, California, Alaska, Colorado, New Mexico, Oklahoma, Wyoming, Kansas, Utah and Montana). A *Dallas Morning News* report focused on how the resulting contamination of groundwater and soils has affected agricultural and ranching. In one case, wastewater from pits seeped beneath a cotton and nut farm near Bakersfield, California and forced the grower to remove 2,000 acres from production. In western Texas, pipeline failures and illegal dumping of frack waste contaminated ranches and pastures.[1650]

- May 2, 2015 – The *Los Angeles Times* reported that farmers in Kern County, California purchased over 21 million gallons per day of treated oil field wastewater to use for crop irrigation. The article identified lingering questions about chemicals remaining after treatment and their potential impact both on the crops and those who consume them. Independent testing identified chemicals including acetone and methylene chloride, along with oil, in the treated irrigation water.[1651] Acetone and methylene chloride are powerful industrial solvents that are highly toxic to humans, and samples of the wastewater contained concentrations of both that were higher than those seen at oil spill disaster sites. (Chevron's own report confirmed the presence of acetone, benzene, and xylene, though in lesser concentrations; Chevron did not appear to test for methylene chloride.[1652]) Broader testing requirements involving chemicals covered under California's new fracking disclosure regulations went into effect June 15, 2015.[1653]

- April 24, 2015 – Unconventional technologies in gas and oil extraction facilitated the drilling of an average of 50,000 new fractured wells per year in North America over the past 15 years. An interdisciplinary study published in *Science* demonstrated that the accumulating land degradation has resulted in continent-wide impacts, as measured by the reduced amount of carbon absorbed by plants and accumulated as biomass. This is a robust metric of essential ecosystem services, such as food production, biodiversity, and wildlife habitat, and its loss "is likely long-lasting and potentially permanent." The land area occupied by well pads, roads, and storage facilities built during this period is

[1649] Potter County Today, "Shale Gas Impact on Agriculture 'Profound,'" November 23, 2015, https://web.archive.org/web/20151206011350/http://today.pottercountypa.net/shale-gas-impact-on-agriculture-profound/.
[1650] J. Flesher, "Fatal Flow: Brine from Oil, Gas Drilling Fouls Land, Kills Wildlife at Alarming Rate," *The Dallas Morning News*, October 25, 2015, sec. News, https://www.dallasnews.com/news/2015/10/25/fatal-flow-brine-from-oil-gas-drilling-fouls-land-kills-wildlife-at-alarming-rate/.
[1651] Julie Cart, "Central Valley's Growing Concern: Crops Raised with Oil Field Water," *Los Angeles Times*, May 2, 2015, sec. California, https://www.latimes.com/local/california/la-me-drought-oil-water-20150503-story.html.
[1652] Amec Foster Wheeler Environment & Infrastructure, Inc., "Reclaimed Water Impoundments Sampling, Cawelo Water District Ponds, Kern River Oil Field, Kern County, California, Prepared for Chevron U.S.A. Inc.," Technical Report, June 15, 2015.
[1653] Daniel Ross, "Has Our Food Been Contaminated by Chevron's Wastewater?," *Truthout*, June 19, 2015, sec. Environment, https://truthout.org/articles/has-our-food-been-contaminated-by-chevron-s-wastewater/.

approximately three million hectares, roughly the land area of three Yellowstone National Parks. The authors concluded that new approaches to land use planning and policy are "necessary to achieve energy policies that minimize ecosystem service losses."[1654]

- January 26, 2015 – Two Colorado scientists performed a detailed analysis of vegetative patterns—followed chronologically—over a selected group of well pads in Colorado managed by the U.S. Bureau of Land Management, including two undisturbed reference sites. They documented the disturbance of plant and soil systems linked to contemporary oil and gas well pad construction, and found that none of the oil and gas well pads included in the study returned to pre-drilling condition, even after 20-50 years. Full restoration may require decades of intensive effort.[1655]

- October 14, 2014 – State documents obtained by the Center for Biological Diversity show that almost three billion gallons of fracking wastewater have been illegally dumped into central California aquifers that supply drinking water and farming irrigation. The California Water Board confirmed that several oil companies used at least nine of 11 injection wells that connect with high-quality water sources for disposal of fracking wastewater, which included high levels of arsenic, thallium, and nitrates. The California Division of Oil, Gas and Geothermal Resources has shut down 11 oil field injection wells and is scrutinizing almost 100 others for posing a "danger to life, health, property, and natural resources." At least one farming company has sued oil producers in part for contaminating groundwater that farms use for irrigation.[1656]

- September 6, 2014 – *Al Jazeera America* examined the challenges that North Dakota farmers are facing in light of wastewater spills from oil and gas development. Notably, in heavily drilled Bottineau County, some levels of chloride, from sites where an estimated 16,800-25,200 gallons of wastewater had seeped into the ground, were so high that they exceeded the levels measurable with the North Dakota Department of Health's test strips. State records, testimonies from oil workers and various residents, and the decades-long failure of contaminated fields to produce crops indicate that wastewater spills are a significant hazard in the current fracking boom.[1657]

- August 6, 2014 – The Pennsylvania Department of Environmental Protection (PA DEP) found that leaks of fracking wastewater from three impoundments contaminated soil and groundwater. The findings prompted the state to issue a violation and increase testing.[1658]

[1654] B. W. Allred et al., "Ecosystem Services Lost to Oil and Gas in North America," *Science* 348, no. 6233 (2015): 401–2, https://doi.org/10.1126/science.aaa4785.
[1655] Tamera J. Minnick and Richard D. Alward, "Plant–Soil Feedbacks and the Partial Recovery of Soil Spatial Patterns on Abandoned Well Pads in a Sagebrush Shrubland," *Ecological Applications* 25, no. 1 (2015): 3–10, https://doi.org/10.1890/13-1698.1.
[1656] Sandy Dechert, "Fracking Wastewater Spoils California Drinking, Farm Supplies," CleanTechnica, October 14, 2014, https://cleantechnica.com/2014/10/14/fracking-wastewater-spoils-california-drinking-farm-supplies/.
[1657] Laura Gottesdiener, "In Shadow of Oil Boom, North Dakota Farmers Fight Contamination," *Al Jazeera America*, September 6, 2014, http://america.aljazeera.com/articles/2014/9/6/north-dakota-wastewaterlegacy.html.
[1658] Don Hopey, "State: Fracking Waste Tainted Groundwater, Soil at Three Washington County Sites," *Pittsburgh Post-Gazette*, August 6, 2014, https://www.post-gazette.com/local/washington/2014/08/06/Pa-finds-tainted-water-soil-at-three-Washington-County-shale-sites/stories/201408050198.

- August 5, 2014 – Michelle Bamberger, a veterinarian and researcher, and Robert Oswald, a professor of molecular medicine at Cornell University, published a book that describes their research into the impacts of drilling and fracking on agriculture and animal health. They detail results of 24 case studies from six gas drilling states, including follow-up on cases they previously published in the peer-reviewed literature, raising concerns about the effects of drilling and fracking on agriculture and the health of animals.[1659]

- August 1, 2014 – At least 19,000 gallons of hydrochloric acid spilled during completion of a fracking well on an alfalfa farm in Kingfisher County, Oklahoma. The Oklahoma Corporation Commission reported concerns about rain pushing chemical runoff into a nearby creek that flows into the town of Hennessey's water system. The responsible company, Blake Production, planned to pay for the alfalfa crop for six years. The landowner and a neighbor were pursuing litigation.[1660]

- May 3, 2014 – In an analysis of state data from Colorado, the *Denver Post* reported that fracking related to oil and gas drilling is putting soil quality and farmlands at risk due to significant amounts of toxic fluids penetrating the soil. According to report, 578 spills were reported in 2013, which means that, on average in the state, a gallon of toxic liquid penetrates the ground every eight minutes. Colorado State University soil scientist Eugene Kelly, said that the overall impact of the oil and gas boom "is like a death sentence for soil."[1661]

- November 28, 2012 – In conjunction with the Food & Environment Reporting Network, *The Nation* reported that serious risks to agriculture caused by fracking are increasing across the country and linked these concerns to risks to human health.[1662]

- January 2012 – A study of gas drilling's impacts on human and animal health concluded that the drilling process may lead to health problems. The study reported and analyzed a number of case studies, including dead and sick animals in several states that had been exposed to drilling or hydraulic fracturing fluids, wastewater, or contaminated ground or surface water.[1663] The researchers cited 24 cases in six states where animals and their owners were potentially affected by gas drilling. In one case, a farmer separated 96 head of cattle into three areas, one along a creek where fracking wastewater was allegedly dumped and the remainder in fields without access to the contaminated creek; the farmer

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[1659] Michelle Bamberger and Robert Oswald, *The Real Cost Of Fracking: How America's Shale Gas Boom Is Threatening Our Families, Pets, and Food* (Beacon Press, 2015).
[1660] Kim Passoth, "Major Oil Field Spill in Kingfisher Co.," *KOCO News 5 ABC*, August 2, 2014, sec. News, https://www.koco.com/article/major-oil-field-spill-in-kingfisher-co/4299547.
[1661] Bruce Finley, "Colorado Faces Oil Boom 'Death Sentence' for Soil, Eyes Microbe Fix," *The Denver Post*, May 3, 2014, https://www.denverpost.com/2014/05/03/colorado-faces-oil-boom-death-sentence-for-soil-eyes-microbe-fix/.
[1662] Elizabeth Royte, "Fracking Our Food Supply," *The Nation*, November 28, 2012, https://www.thenation.com/article/archive/fracking-our-food-supply/.
[1663] Michelle Bamberger and Robert E. Oswald, "Impacts of Gas Drilling on Human and Animal Health," *New Solutions: A Journal of Environmental and Occupational Health Policy* 22, no. 1 (2012): 51–77, https://doi.org/10.2190/NS.22.1.e.

found that, of the 60 head exposed to the creek, 21 died and 16 failed to produce, whereas the unexposed cattle experienced no unusual health problems. In another case, a farmer reported that of 140 head of cattle exposed to fracking wastewater, about 70 died, and there was a high incidence of stillborn and stunted calves in the remaining cattle.[1664]

- January 2011 – U.S. Forest Service researchers reported dramatic negative effects on vegetation caused by the drilling and fracking of a natural gas well in an experimental forest in northeastern West Virginia. In June 2008, the researchers found browning of foliage near the well pad, a lack of ground foliage, and that many trees nearby had dropped their foliage. They attributed these impacts to the loss of control of the wellbore on May 29, 2008, which caused an aerial release of materials from the well. Trees showed no apparent symptoms the following summer. However, the researchers also found "dramatic impacts on vegetation" where drilling and fracking wastewater had been sprayed on the land as a disposal technique following completion of the well. Just after the spraying of approximately 60,000 gallons of wastewater at the first disposal site, the Forest Service researchers found 115 damaged trees and other evidence of harm. This figure grew to 147 trees almost a year later. At a second site, where about 20,000 gallons of wastewater was sprayed, the damage was less dramatic, yet the researchers still found "considerable leaf browning and mortality of young northern red oak seedlings." The researchers concluded that the spraying of the drilling fluids resulted in an "extreme" dose of chlorides to the forest.[1665]

- May 2010 – Pennsylvania's Department of Agriculture quarantined 28 cows in Tioga County after the animals wandered through a spill of drilling wastewater and may have ingested some of it. The Department was concerned that beef eventually produced from the cows could be contaminated as a result of any exposure. In May 2011, only ten yearlings were still quarantined, but the farmer who owned the cows, Carol Johnson, told National Public Radio that of 17 calves born to the quarantined cows in the spring of 2011, only six survived, and many of the calves that were lost were stillborn. "They were born dead or extremely weak. It's highly unusual," she said, continuing, "I might lose one or two calves a year, but I don't lose eight out of eleven."[1666]

- March 2010 – A Pennsylvania State Extension analysis of dairy farms in the state found a decline in the number of dairy cows in areas where fracking was prevalent. Pennsylvania counties that had both more than 10,000 dairy cows and more than 150 Marcellus Shale wells experienced a 16-percent decline in dairy cows between 2007 and 2010.[1667]

[1664] Krishna Ramanujan, "Study Suggests Hydrofracking Is Killing Farm Animals, Pets," *Cornell Chronicle*, March 7, 2012, https://news.cornell.edu/stories/2012/03/reproductive-problems-death-animals-exposed-fracking.
[1665] Mary Beth Adams et al., "Effects of Development of a Natural Gas Well and Associated Pipeline on the Natural and Scientific Resources of the Fernow Experimental Forest," General Technical (U.S. Department of Agriculture, January 2011), https://www.fs.fed.us/nrs/pubs/gtr/gtr_nrs76.pdf.
[1666] Susan Phillips, "Burning Questions: Quarantined Cows Give Birth to Dead Calves," *State Impact Pennsylvania*, September 27, 2011, https://stateimpact.npr.org/pennsylvania/2011/09/27/burning-questions-quarantined-cows-give-birth-to-dead-calves/.
[1667] Penn State Extension, "Pennsylvania Dairy Farms and Marcellus Shale, 2007-2010," *Penn State Extension*, March 2010, https://extension.psu.edu/pennsylvania-dairy-farms-and-marcellus-shale-2007-2010.

- April 28, 2009 – Seventeen cows in Caddo Parish, Louisiana died within one hour after apparently ingesting hydraulic fracturing fluids spilled at a well that was being fractured. "It seemed obvious the cattle had died acutely from an ingested toxin that had drained from the 'fracking' operation going on at the property," Mike Barrington, a state veterinarian said in a document obtained from the state Department of Environmental Quality by the *Times-Picayune*.[1668, 1669]

- August 1977 – A paper in the *Journal of Arboriculture* described how natural gas leaks in soil can damage plants and crops. The paper notes that vegetation dies in the vicinity of natural gas leaks. Due to the oxidation of methane by methane-consuming bacteria, gas leaks drive down the oxygen concentration to extremely low levels and cause carbon dioxide concentration to rise. The resulting low oxygen concentration is the greatest contributing factor in the death of trees and other vegetation near natural gas leaks.[1670]

[1668] KSLA, "Cows in Caddo Parish Fall Dead near Gas Well," *KSLA News*, April 29, 2009, https://www.ksla.com/story/10268585/cows-in-caddo-parish-fall-dead-near-gas-well/.
[1669] Mark Schleifstein, "Haynesville Natural Gas Field Is the Most Productive in the U.S.," *The New Orleans Advocate*, March 27, 2011, https://www.nola.com/news/politics/article_fbdcb467-382d-52a8-90e7-7dc667edecb4.html.
[1670] Spencer H. Davis Jr., "The Effect of Natural Gas on Trees and Other Vegetation," *Journal of Arboriculture* 3, no. 8 (1977): 153–54.

Threats to the climate system

Natural gas is not a climate-friendly fuel. Methane, which escapes from all parts of the natural gas extraction and distribution system, is a powerful greenhouse gas that traps 86 times more heat than carbon dioxide over a 20-year time frame. According to the best available evidence, fuel-switching that replaces coal with natural gas to generate electricity offers no clear climate benefits and likely represents a step backwards. As is now documented in many studies, fugitive methane emissions from U.S. drilling and fracking operations are omnipresent, much higher than previously supposed, and a main driver of rising methane emissions in the United States. The science is settled on these facts.

A significant proportion of fracking-related methane leaks are not preventable through engineering fixes. Indeed, some represent intentional venting during routine maintenance or during attempts to control pressure and prevent explosions during malfunctions. Venting takes place at all points along the supply chain, from well pads, pipelines, and compressor stations to liquefied natural gas (LNG) export terminals. Storage tanks, compressor stations, and unlit flare stacks are emerging as significant sources of methane emissions, according to studies published in both Canada and the United States. The problem of methane leakage appears to be getting worse rather than better with newer fracking sites in the Permian Basin leaking more methane than older sites. A 2018 analysis of methane emissions from the U.S. oil and gas supply chain found leakage rates 60 percent higher than reported by the U.S. Environmental Protection Agency (EPA). A 2023 analysis using both satellite and surface observations found leakage rates 70 percent higher than EPA estimates. Collectively, a range of studies disprove the claim that natural gas is a transitional "bridge" fuel that can lower greenhouse gas emissions while renewable energy solutions are developed.

A sharp rise in global atmospheric methane concentrations began in 2007 and has accelerated since 2014. The causes for this spike are not yet fully understood and likely include both biogenic sources (livestock, agriculture, wetlands, landfills, forest fires) and fossil fuel sources. As both satellite and ground measurements reveal, U.S. methane emissions are responsible for 30-60 percent of the recent upsurge in global atmospheric methane concentrations. Most of this excess methane appears to represent fugitive emissions from U.S. oil and gas operations, which underwent its own surge in activity during the same time period.

Several lines of evidence point to the important role of drilling and fracking operations in driving greenhouse gas emissions upward. These include the atmospheric pattern of increased methane concentrations directly over intensively fracked areas of the United States; sharp upticks in global methane and co-occurring ethane levels that correspond to the advent of the U.S. shale gas and oil boom; and documentation of large pulses of methane released from storage facilities and other "super-emitting" sites. Reducing atmospheric methane is key to reducing the rate of global warming and limiting temperature rise to 1.5 º C according to a 2021 assessment from the United Nations, which identified the fossil fuel industry as the sector with the greatest potential to cut methane emissions rapidly.

The widely touted claim that the U.S. shale gas and oil boom has contributed to recent declines in carbon dioxide emissions in the United States has been invalidated by research showing that

almost all the reductions in CO_2 emissions between 2007 and 2009 were the result of economic recession rather than coal-to-gas fuel switching. Other lines of research show that expanded use of natural gas impedes rather than encourages investments in, and deployment of, renewable energy infrastructure. In sum, fracking, which enables the extraction of oil and gas from shale, is a major driver of rising methane emissions, is incompatible with climate stability, and stands as an obstacle to rapid decarbonization that the goal of climate stability requires.

- May 19, 2023 – The Paris Agreement has set 1.5ºC as the limit for global warming. This goal cannot be reached without slashing methane emissions by at least 40-45 percent by 2030 when compared with 2020 levels. Currently, methane emissions are underregulated, but also the effectiveness of the regulatory practices in place are not well understood. A first-ever global review of the 281 existing methane mitigation measures across energy, waste, and agricultural sectors around the world found that only 13 percent of methane emissions are covered by existing policies and that these are not uniformly distributed across all sources. For example, of the 110 methane mitigation policies covering methane emissions from fossil fuels that were identified in this review, only six targeted downstream and end-use emission with the vast majority focused on extraction, gathering, and distribution. Only three policies aimed to reduce methane emissions from abandoned and inactive wells via identifying and repairing failing plugs. The researchers also found that fossil fuel policies, which rely more on financial incentives, are less stringent than those governing methane emissions from livestock and waste. "Methane reduction is still perceived as a choice rather than a necessity complementing the ongoing decarbonization efforts focused largely on CO2." Further, because most methane reduction policies are based on estimates rather than direct measures of methane, their effectiveness is unclear.[1671]

- April 17, 2023 – The United States is the leading methane emitter in the world, contributing 15 percent of the world's gas- and oil-derived methane emissions. An international team of researchers using satellite observations and surface observations to quantify temporal trends in U.S. emissions from the oil and gas industry found a significant underestimation in the national inventory of oil and gas methane emissions. In the United States, emissions from 2010-2019 were 70 percent higher than the estimates reported by the U.S. Environmental Protection Agency. In general, methane emissions rose and fell during this decade in ways that tracked production rates, active well counts, and new wells drilled in three major U.S. shale regions, demonstrating that drilling and fracking activities are a main driver of methane emissions in the United States. U.S. methane emissions rose between 2010-2014, decreased from 2014-2017, and then rose again after 2017. The 2014-2017 decline corresponds to a reduction in new wells drilled during that period and new regulations requiring the capture of gas from the completion-

[1671] Maria Olczak, Andris Piebalgs, and Paul Balcombe, "A Global Review of Methane Policies Reveals That Only 13% of Emissions Are Covered with Unclear Effectiveness," *One Earth* 6, no. 5 (May 2023): 519–35, https://doi.org/10.1016/j.oneear.2023.04.009.

venting step of hydraulic fracturing. The 2017-2019 surge was accompanied by an upswing in oil and gas extraction activities during that period.[1672]

- January 31, 2023 – Using aerial remote sensing data from four surveys plus activity data on oil and gas production, a research team quantified methane emission intensity from oil and gas operators in the Permian basin and made comparisons among them. The results showed a wide range of emission intensities during several periods of time. Half of all operators showed improvements over time with a 50 percent reduction in super-emitter intensity between 2019 and 2021. The authors note that they did not consider the significant emissions from the midstream sector (for example, pipelines and compressor stations).[1673]

- December 22, 2022 – The U.K.'s National Atmospheric Emissions Inventory (NAEI) reports greenhouse gas emissions from the United Kingdom to the United Nations. A critical evaluation of the methods used to collect data for this inventory demonstrated that it significantly underestimates methane from the extraction and transport of oil and natural gas. The U.K. inventory relies on direct, surface-level measurements of leaks. A reassessment using an integrated approach that combines direct measurements with airborne monitoring and published data estimates the U.K.'s 2019 methane emissions at five times the NAEI estimate. The authors call for funding of efforts to improve the detection of methane leakage via remote sensing.[1674]

- November 5, 2022 – A study using optical gas imaging cameras to measure fugitive and vented methane leaks at fifteen shale gas well pads in West Virginia found that pneumatic devices and liquid storage tanks had the highest leak rates, with twelve of the fifteen sites showing tank-related leaks. While reporting data and permits assume 100 percent capture efficiency for storage tanks, the researchers estimated that their real-life capture efficiencies ranged from 63 - 92 percent.[1675]

- September 30, 2022 – A commentary on recent findings on gas flaring [see entry below] noted that most oil and gas extraction operations provide no direct tracking of their methane removal efficiency of their flares—nor even report their operational status. Further, flares are often used for a variety of reasons unrelated to emergencies and safety precautions, which are their intended purpose. The authors called for improved monitoring and better models to guide improvements in flare design and operation. "Together, satellites, surface sensors, and models can provide more accurate assessments

[1672] Xiao Lu et al., "Observation-Derived 2010-2019 Trends in Methane Emissions and Intensities from US Oil and Gas Fields Tied to Activity Metrics," *Proceedings of the National Academy of Sciences* 120, no. 17 (April 25, 2023): e2217900120, https://doi.org/10.1073/pnas.2217900120.
[1673] Benjamin Hmiel et al., "Empirical Quantification of Methane Emission Intensity from Oil and Gas Producers in the Permian Basin," *Environmental Research Letters* 18, no. 2 (February 1, 2023): 024029, https://doi.org/10.1088/1748-9326/acb27e.
[1674] Stuart N. Riddick and Denise L. Mauzerall, "Likely Substantial Underestimation of Reported Methane Emissions from United Kingdom Upstream Oil and Gas Activities," *Energy & Environmental Science*, 2023, 10.1039.D2EE03072A, https://doi.org/10.1039/D2EE03072A.
[1675] Derek Johnson et al., "Methane Emissions from Oil and Gas Production Sites and Their Storage Tanks in West Virginia," *Atmospheric Environment: X* 16 (December 2022): 100193, https://doi.org/10.1016/j.aeaoa.2022.100193.

of the role that improved flaring efficiency plays in overall oil and gas emissions and future mitigation efforts…. As the global climate crisis continues to worsen, resolving the flaring problem in this decisive decade is among the easiest routes to help mitigate the problem."[1676]

- September 29, 2022 – Unlit flares and inefficient gas flaring are responsible for a fivefold increase in methane emissions above present assumptions and, taken together, constitute 4 to 10 percent of total U.S. oil and gas methane emissions, according to an observational study that used airborne sampling of 300 different flares to calculate flare efficiency in the Permian, Bakken, and Eagle Ford shale basins. The findings of this study showed that flaring by U.S. oil and gas operations destroyed, on average, only 87-94 percent of the methane that it attempted to combust. The widely presumed efficiency of flaring is 98 percent. At the same time, unlit flares—most often the result of flames extinguishing or never igniting in the first place—directly release plumes of unburned gas to the atmosphere and erode efficiency further. By both pathways, inefficient and unlit natural gas flares are responsible for releasing into the atmosphere a quantity of methane that is five times higher than amounts previously assumed in the EPA greenhouse gas inventory. Addressing unlit flares presents a simple and cost-effective methane mitigation opportunity.[1677]

- September 13, 2022 – A study using a tiered observing system of airborne imaging spectrometers identified point sources of methane emissions in five intensely fracked regions the United States: the San Joaquin Valley in California; the Uinta Basin in Utah; the Denver-Julesburg and Permian Basins in Texas and New Mexico; and the Marcellus Basin in Appalachia. By measuring the fluctuations in emissions across time and comparing these point source emissions to the fluxes in methane emissions across the entire basins, the researchers determined that point sources make up, on average, 40 percent of the regional flux. In other words, a proportionally few methane super-emitters contribute a disproportionate fraction of total emissions across multiple shale basins in the United States. "These results show that a significant climate benefit can be realized by specific isolation and remediation of relatively few sources."[1678]

- March 23, 2022 – A Stanford University study that combined aerial data with surface-level measurements calculated methane emissions at 9.4 percent of gas production in New Mexico's portion of the intensely fracked Permian Basin, one of the most active oil producing regions in the world. This leakage rate is 6.7 times higher than the EPA's estimate of 1.4 percent. "The clear impact of large emissions found by this study suggests

[1676] Riley Duren and Deborah Gordon, "Tackling Unlit and Inefficient Gas Flaring," *Science* 377, no. 6614 (September 30, 2022): 1486–87, https://doi.org/10.1126/science.ade2315.
[1677] Genevieve Plant et al., "Inefficient and Unlit Natural Gas Flares Both Emit Large Quantities of Methane," *Science* 377, no. 6614 (September 30, 2022): 1566–71, https://doi.org/10.1126/science.abq0385.
[1678] Daniel H. Cusworth et al., "Strong Methane Point Sources Contribute a Disproportionate Fraction of Total Emissions across Multiple Basins in the United States," *Proceedings of the National Academy of Sciences* 119, no. 38 (September 20, 2022): e2202338119, https://doi.org/10.1073/pnas.2202338119.

that estimates from ground-based methane surveys may be underestimating total emissions by missing low-frequency, high-impact large emissions."[1679]

- February 1, 2022 – The west coast of Turkmenistan on the shore of the Caspian Sea is one of the world's largest methane hotspots. A research team combined three sets of satellite data to evaluate individual methane emission sources in this area. Between January 2017 and November 2020, the team identified 29 super-emitters. All 29 of them were point sources linked to oil extraction activities, with 24 of 29 representing unlit flares venting unburned methane. Two other sources represent pipeline leaks. The three other remaining emission points are from unknown sources. Identifying and remediating high-emitting sources are fundamental in short-term mitigation.[1680]

- November 16, 2021 – Using multi-year observations and atmospheric modeling, a study of the intensely drilled and fracked Uinta Basin in northern Utah found that 6 to 8 percent of the total gas extracted escaped as atmospheric emissions. This leakage rate, among the highest in the United States, remained constant between 2015 and 2020, even as gas production in the region declined over the same period.[1681]

- August 5, 2021 – A study using a new bottom-up emissions estimation tool that is on a comprehensive database of leakage from different oil and gas production components found that liquid storage tanks are much larger emitters of methane than previous appreciated. These results help explain the disparity between field measurements of methane emissions and official greenhouse gas inventory estimates generated by the EPA.[1682]

- July 12, 2021 – Combining two different methods of measurement, Canadian researchers found that methane emissions from oil and gas extraction operations in British Columbia are 1.6 to 2.2 times higher than estimated by Canada's current federal inventory. Their results showed that more than half of emissions could be attributed to three main sources: tanks (24 percent); compressors (15 percent); and unlit flares (13 percent). The researchers wrote, "In particular, tank emissions appear much more important than current inventories suggest and unlit flares are a second important gap, bolstering observations from recent helicopter measurements in the Permian basin." This new combined-measurement approach, which matched optical gas imaging (OGI) cameras on the ground with aerial surveys, greatly improved accuracies in sites where OGI surveys alone are unreliable. Total emissions measured by the aerial survey were 18 times higher

[1679] Yuanlei Chen et al., "Quantifying Regional Methane Emissions in the New Mexico Permian Basin with a Comprehensive Aerial Survey," *Environmental Science & Technology*, March 23, 2022, acs.est.1c06458, https://doi.org/10.1021/acs.est.1c06458.
[1680] Itziar Irakulis-Loitxate et al., "Satellites Detect Abatable Super-Emissions in One of the World's Largest Methane Hotspot Regions," *Environmental Science & Technology* 56, no. 4 (February 15, 2022): 2143–52, https://doi.org/10.1021/acs.est.1c04873.
[1681] John C. Lin et al., "Declining Methane Emissions and Steady, High Leakage Rates Observed over Multiple Years in a Western US Oil/Gas Production Basin," *Nature Scientific Reports* 11, no. 1 (2021): 22291, https://doi.org/10.1038/s41598-021-01721-5.
[1682] Jeffrey S. Rutherford et al., "Closing the Methane Gap in US Oil and Natural Gas Production Emissions Inventories," *Nature Communications* 12, no. 1 (2021): 4715, https://doi.org/10.1038/s41467-021-25017-4.

than those recorded by the OGI cameras. In the case of leaking tanks, for example, disparities between ground and aerial measurements of methane emission rates differ by a factor of more than 40: whereas the ground survey mean rate, as estimated by OGI, was 1.3 kg/h, the rate estimated by aerial surveys was 48.3 kg/h. Further, methane emissions from unlit flairs are inherently difficult to capture by OGI camera, and this study's aerial measurements showed that they were a significant contributor to methane emissions. Similarly, the study found that "unburned methane entrained in natural gas engine-driven compressor exhaust," also not easily measurable with OGI, is responsible for much of the total emissions at compressor stations. Conversely, the aerial survey identified 10-fold fewer total sources of emissions than did OGI, suggesting that the two methodologies are prone to different types of inaccuracies in data collection. The research team concluded that "policy and regulations that rely on OGI surveys alone risk missing a significant portion of total emissions."[1683]

- June 30, 2021 – The Permian Basin is now the largest oil and gas-producing basin in the United States. Using high-resolution satellite measurements collected over several days, an international team of researchers identified 37 different "extreme" methane plumes (that is, those emitting more than 500 kg of methane per hour) and attributed them to specific types of infrastructure. The results showed that newer facilities—those starting production in 2018 or later—contributed more extreme emissions than older facilities. Specifically, extreme emissions occurred 2.6 times more frequently for new facilities than old, and the amount of methane emitted by new facilities is twice that of older facilities. "This result supports the speculation that recently developed wells and infrastructure associated with these wells are the major methane emitters in the Permian basin, which is likely due to a faster development of gas extraction methods than of storage and processing capabilities." The results showed that fully half of all methane emissions originated from compressor stations, 24 percent from tank batteries, 21 percent from flaring, and 6 percent from wells themselves. The high proportion of emissions (21 percent in terms of both number of plumes and amount of methane emitted) that come from flare stacks was a surprising discovery. "Such high emission rates can only be explained by inefficient or malfunctioning flaring operations…. Our results suggest that the rapid installation of new O&G production facilities in the Permian basin might not be counterbalanced by sufficient parallel development of gas gathering and processing infrastructure, which would lead to a high concentration of extreme emissions in the region due to issues such as unlit associated gas flares."[1684]

- June 24, 2021 – At least 123 oil and gas sites in Austria, Czech Republic, Germany, Hungary, Italy, Poland and Romania emit methane, according to data released by the international nonprofit organization Clean Air Task Force (CATF) and reported by Reuters. At the time of reporting, the European Union did not regulate methane leaks and vents to the atmosphere and reporting requirements were limited to only some of the

[1683] David R. Tyner and Matthew R. Johnson, "Where the Methane Is: Insights from Novel Airborne LiDAR Measurements Combined with Ground Survey Data," *Environmental Science & Technology* 55 (2021): 9773–83, https://doi.org/10.1021/acs.est.1c01572.
[1684] Itziar Irakulis-Loitxate et al., "Satellite-Based Survey of Extreme Methane Emissions in the Permian Basin," *Science Advances* 7, no. 27 (2021): eabf4507, https://doi.org/10.1126/sciadv.abf4507.

individual nation states. Hence, no laws were broken by companies responsible for these emissions. According to James Turitto, who filmed the emissions for CATF, 90 percent of the sites visited in the Czech Republic, Hungary, Italy, Poland, and Romania were emitting methane, while the frequency of leaking sites in Germany and Austria was lower. Using independent experts to review a selection of the CATF infrared thermography, Reuters reported that a significant proportion of these emissions was avoidable with commercially available measurement and abatement technology. While the omnipresence of leaks in Europe's gas system currently resembles that of the United States, said Reuters, proposed EU restrictions on venting and flaring methane have put energy companies on notice. These rules will not go into force until 2023 or thereafter.[1685]

- June 15, 2021 – Newly launched and soon to be deployed satellites will continue to sharpen identification of methane leaks from oil and gas operations, filling gaps left by ground-based sensors and aerial surveys, according to an analysis by *Yale Environment 360*. While earlier generations of satellites were consistently unable to link specific sources with emissions data, newer satellites have been able, despite the pandemic, to match recent rises in methane releases to their origins in Russia, Turkmenistan, and Canada.[1686]

- June 2, 2021 – A report funded by Bank of America and developed by the energy consultancy M.J. Bradley & Associates—in collaboration with the non-profit organizations Ceres and the Clean Air Task Force—looked at the relationship between methane emissions and oil and gas extraction volumes. An analysis of 295 oil and gas producers that report data to the EPA under its Greenhouse Gas Reporting Program showed that the magnitude of methane emissions was not a function of a company's production levels.[1687] Indeed, the largest methane emitter in the United States, Hilcorp Energy, emitted 50 percent more methane from its operations than did Exxon Mobil, even though Hilcorp pumps far less oil and gas. Four other relatively unknown companies—Terra Energy Partners, Flywheel Energy, Blackbeard Operating and Scout Energy—each self-reported more methane emissions than many top producers. As further described in reporting by the *New York Times* small, privately held drilling companies that are buying up high-polluting assets from larger companies are rapidly becoming the nation's highest emitters of methane and other greenhouse gases. In this way, oil and gas majors are able to remove highly leaky facilities from their books. "Hilcorp's methane

[1685] Kate Abnett and Shadia Nasralla, "EXCLUSIVE: Gas Infrastructure Across Europe Leaking Planet-Alarming Methane," Reuters, June 24, 2021, https://www.reuters.com/business/environment/exclusive-gas-infrastructure-across-europe-leaking-planet-warming-methane-video-2021-06-24/.
[1686] Cheryl Katz, "In Push to Find Methane Leaks, Satellites Gear Up for the Hunt," Yale Environment 360, June 15, 2021, https://e360.yale.edu/features/in-push-to-find-methane-leaks-satellites-gear-up-for-the-hunt.
[1687] Robert LaCount et al., "Benchmarking Methane and Other GHG Emissions of Oil & Natural Gas Production in the United States" (M.J. Bradley & Associates, June 2021), https://www.mjbradley.com/sites/default/files/OilandGas_BenchmarkingReport_2021.pdf.

emissions intensity, or leak rate, was almost six times higher than the average of the top 30 producers, largely caused by high emissions from its aging San Juan operations."[1688]

- June 1, 2021 – After a brief pandemic-related drop, fracking activities in the Permian Basin in West Texas once again rebounded and now represent the number one source of methane emissions in the United States. Continued expansion of these operations threatens "any credible US response to the climate crisis," according to investigative reporter Rebecca Leber, who described several formidable obstacles to reining in this "ticking time bomb." Sited on land entirely state-owned or privately held, Permian Basin fracking operations are not governed by future regulations that might restrict new federal leasing. Further, economic incentives do not constrain methane emissions. Permian producers, for whom oil brings a bigger profit, largely consider natural gas a waste product and, hence, intentionally release methane via unlit or burning flares in the absence of any state-based regulation. Leber notes that the EPA could be authorized to intervene but has limited resources for doing so. Another strategy, which goes beyond limiting emissions to addressing production, seeks to interrupt industry's export plans, on which the industry is relying in light of US market "saturation." Declaring a climate emergency, Leber wrote, may be the federal administration's only option to "cut off producers from their global customers" if Congress does not enact appropriate climate measures. "There is a narrow pathway to do this. In 2015, Congress lifted a crude-oil export ban but kept a 'get-out' clause. It allows a president to suspend these exports by declaring a national emergency. Other kinds of exports, like liquefied natural gas, would require permitting from FERC, an independent energy regulatory agency, and the Department of Energy."[1689]

- May 27, 2021 – Episodic releases of methane from various types of fracking infrastructure create monitoring challenges. Researchers investigated the potential impact of variations over time in emissions from known "super-emitter" sites by performing 17 methane audits at one such natural gas extraction site over a four-year time period, from 2016 to 2020. Results revealed high temporal variability, with minimum and maximum levels varying by a factor of 560. These results suggest that substantial methane emissions may go undetected by infrequent audits. "These data highlight that single snapshots in time from direct methane quantification audits could significantly overpredict or underpredict methane emissions on an annual basis." The results also highlighted the importance of storage tanks as a potential source of methane emissions. At this super-emitting facility, tank emissions represented the majority of emissions for eight audits (54.7−99.7 percent by mass) and overall represented 91 percent of all measured methane emissions.[1690]

[1688] Hiroko Tabuchi, "Here Are America's Top Methane Emitters. Some Will Surprise You," *The New York Times*, June 2, 2021, https://www.nytimes.com/2021/06/02/climate/biggest-methane-emitters.html?referringSource=articleShare.
[1689] Rebecca Leber, "There's a Ticking Climate Time Bomb in West Texas," *Vox*, June 1, 2021, https://www.vox.com/22407581/gas-texas-biden-climate-change-methane-permian-basin.
[1690] Derek Johnson and Robert Heltzel, "On the Long-Term Temporal Variations in Methane Emissions from an Unconventional Natural Gas Well Site," *ACS Omega* 6, no. 22 (2021): 14200–207, https://doi.org/10.1021/acsomega.1c00874.

- May 6, 2021 – Reducing atmospheric methane is key to reducing the rate of global warming and limiting temperature rise to 1.5º C, and the fossil fuel industry has the greatest potential to cut methane emissions rapidly, according to the latest United Nations assessment report. The assessment found the fossil fuel industry is responsible for 35 percent of human-caused emissions and identified "readily available targeted measures" that could reduce emissions 30 percent by 2030. The industry could implement up to 80 percent of these measures at negative or low cost. The report states that methane mitigation must take place even alongside decarbonization strategies, and that "expansion of natural gas infrastructure and usage is incompatible with keeping warming to 1.5° C." In addition to the climate-related urgency of reducing this powerful, short-lived climate pollutant, the report points to other reasons for global action on methane, including its contribution to the formation of ground-level ozone. The assessment "found that every million tonnes (Mt) of methane reduced prevents approximately 1,430 annual premature deaths due to ozone globally."[1691]

- May 4, 2021 – A U.S. team of researchers analyzed the climate benefits of rapidly reducing methane emissions across all known sectors, which would improve the ability to limit climate damages in the near term. Using a validated model for assessing greenhouse gas-induced climate change, they found that pursuing all known mitigation measures now could slow the global-mean rate of near-term warming by around 30 percent within the decade and so avoid a quarter of a degree centigrade of additional warming by midcentury. Such an approach would create a path that could prevent a rise in mean global temperatures that would exceed more than half a degree centigrade by end of this century. Conversely, a slow implementation of measures to limit methane may well result in an additional tenth of a degree of warming by midcentury and a five percent faster warming rate when compared to rapid action. Waiting to pursue these measures until midcentury may result in an additional two tenths of a degree centigrade by midcentury and 15 percent faster warming rate. The researchers also note that existing mitigation measures across all sectors (rice, livestock, oil and gas, coal mining, landfills, wastewater), if deployed now, could cut expected 2030 methane emissions in half, with a quarter of these at no net cost. "We find that full deployment of these available mitigation measures by 2030 can slow the rate of global-mean warming over the next few decades by more than 25 percent."[1692]

- April 30, 2021 – In response to announced plans by the Mexican government to reduce oil and gas related methane emissions in the country by 40-45 percent by year 2025 (relative to 2012 levels), a research team used satellite imagery of areas overlying onshore and offshore oil and gas facilities in eastern Mexico to quantify the current magnitude of emissions and better understand the location of their key sources. Data

[1691] United Nations Environment Programme and Climate and Clean Air Coalition, "Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions" (United Nations Environment Programme, May 2021), https://www.unep.org/resources/report/global-methane-assessment-benefits-and-costs-mitigating-methane-emissions.
[1692] Ilissa B. Ocko et al., "Acting Rapidly to Deploy Readily Available Methane Mitigation Measures by Sector Can Immediately Slow Global Warming," *Environmental Research Letters* 16, no. 5 (2021): 054042, https://doi.org/10.1088/1748-9326/abf9c8.

showed substantial methane concentrations along the eastern coastal areas and in Mexico City, with enhanced concentrations of nitrous oxide, attributable to gas flaring, also observed over both onshore and offshore production areas. Estimates of methane emissions from satellite data were nearly double those estimated by ground-based, facilities-level emission inventories. The research team calculated an overall methane loss rate of 4.7 percent for oil and gas extraction operations in eastern Mexico (as compared to a 3.7 percent loss rate in the Texas Permian basin gas and oil fields). High loss rates reveal that Mexico's oil and gas basins have "strong mitigation potential," especially at production sites and processing plants.[1693]

- April 24, 2021 – Reducing methane emissions is required to ward off the worst effects of climate change, according to a *New York Times* review of a forthcoming UN report (see May 6, 2021 entry above). According to the summary obtained by the *Times* in advance, the report will single out the fossil fuel industry as the sector which can make the easiest cuts to methane emissions, at little or no cost. The report will also state that expanding the use of natural gas is very likely incompatible with keeping global warming to 1.5° C.[1694]

- March 22, 2021 – Using satellite observations of atmospheric methane across the entire United States and Mexico, an international team discovered that anthropogenic (human-caused) emissions increased between 2010-2015, rather than decreased, as had been estimated by the EPA. For the oil and gas sector, measured methane emissions were almost twice the level estimated by the EPA's greenhouse gas inventory, with the increase largely driven by the rapid growth of fracking operations in the eastern United States. Emissions from oil and gas production facilities in Mexico were also higher than in the nationally reported inventory. The discrepancies between satellite-generated estimates in this study and the national inventories are likely due to an undercount of all potential sources of emissions and high variability of leakage rates within those sources.[1695] The EPA calculates total emissions by estimating methane leaks from specific types of processes and equipment and then extrapolating, based on the numbers of pieces of that kind of equipment operating across the country. This method, noted lead author Joannes Maasakkers, "makes it really hard to get estimates for individual facilities because it is hard to take into account every possible source of emission." Maasakkers also emphasized that "we shouldn't wait until we fully understand these emissions to start trying to reduce them."[1696]

- January 26, 2021 – Combining satellite data with estimates of methane emissions as determined by aircraft-based measurements above onshore and offshore facilities in

[1693] Lu Shen et al., "Unravelling a Large Methane Emission Discrepancy in Mexico Using Satellite Observations," *Remote Sensing of the Environment* 260 (2021), https://doi.org/10.1016/j.rse.2021.112461.
[1694] Hiroko Tabuchi, "Halting the Vast Release of Methane Is Critical for Climate, U.N. Says," *New York Times*, April 24, 2021, https://www.nytimes.com/2021/04/24/climate/methane-leaks-united-nations.html.
[1695] Joannes D. Maasakkers et al., "2010–2015 North American Methane Emissions, Sectoral Contributions, and Trends: A High-Resolution Inversion of GOSAT Observations of Atmospheric Methane," *Atmospheric Chemistry and Physics* 21 (2021): 4339–56.
[1696] Leah Burrows, "Oil and Natural Gas Production Emit More Methane than Previously Thought," Phys.org, March 26, 2021, https://phys.org/news/2021-03-oil-natural-gas-production-emit.html.

Mexico, an international research team calculated methane leakage rates and compared these findings with estimates from Mexico's national greenhouse gas inventory. Estimates of offshore emissions were an order of magnitude lower than the official inventory estimate, but onshore emission estimates were more than an order of magnitude higher. The results showed that a large proportion of emissions is attributable to flaring. One single facility—an onshore gas-processing complex that receives offshore gas—was responsible for greater emissions than the entirety of the largest offshore production region, "suggesting that offshore-produced associated gas is being transported onshore where it is burned and in the process some released to the atmosphere." The majority of those emissions are from flaring and represents "a substantial waste of gas, enough to cover half the natural gas consumption for the national residential section during 2018." The low combustion efficiency of gas flaring operations also makes them a locally important source of unhealthful air pollutants, including volatile organic compounds, polycyclic aromatic hydrocarbons, carbon monoxide, nitrogen oxides, sulfur oxides, and soot. The researchers urge a greater reliance on empirically estimated methane emissions, along with more effective mitigation policies, especially when communities live in proximity to oil and gas production regions.[1697]

- December 15, 2020 – The U.S. natural gas supply chain is leaking substantially more methane than previously presumed, according to the nonprofit organization Global Energy Monitor's "Gas Index." Compiling data from dozens of studies that have measured methane emissions from all components of the U.S. natural gas system—from oil and gas extraction wells to urban distribution pipelines and within homes and businesses—this analysis calculated full life-cycle methane leakage for 71 U.S. cities. The results showed that, in all cases, methane leakage is more extensive across the system than in many earlier estimates, including the EPA's Greenhouse Gas Inventory, with some cities showing leakage rates over four times higher than EPA estimates. City-by-city results highlight where efforts to fix the gas system can be most effective and how cities can achieve large reductions in emissions by switching homes and other buildings from natural gas to electricity, especially for heating systems. "Electrifying building heating would lead to emissions reductions in many cases… replacing gas heaters with efficient electric heat pumps would lead to emissions cuts in every city evaluated." The ten cities with the leakiest gas supplies are Indianapolis, Los Angeles, Phoenix, Miami, Oklahoma City, Orlando, Boston, Little Rock, Reno, and Tampa.[1698]

- November 5, 2020 – Satellite maps compiled in 2014 revealed an anomalous methane hot spot over the intensely drilled and fracked San Juan Basin that straddles the Colorado and New Mexico border. As part of a follow-up study led by the University of Colorado and the National Oceanographic and Atmospheric Administration's Earth System Research Laboratory in Boulder, a research team investigated daily wind patterns in the region and collected both ground-based and airborne atmospheric data on levels of methane, ethane, and other light-chain carbon concentrations to identify and characterized the sources of the emissions. The results revealed that fossil fuel sources are collectively responsible for

[1697] Daniel Zavala-Araiza et al., "A Tale of Two Regions: Methane Emissions from Oil and Gas Production in Offshore/Onshore Mexico," *Environmental Research Letters* 16 (2021), https://doi.org/10.1088/1748-9326/abceeb.
[1698] Mason Inman, "The Gas Index" (Global Energy Monitor, December 15, 2020), https://thegasindex.org/.

the vast majority (72-85 percent) of the observed methane and ethane over the San Juan Basin, with emissions from coalbed methane and natural gas operations alone contributing 66-75 percent of the methane in the hot spot and with 75 percent of the detected methane originating from operations in New Mexico. Moreover, ground-based measurements and meteorological data illustrate that local methane sources are especially influencing surface air composition at night and in the early morning "when limited air circulation leads to the pooling of emissions near sources, especially in low elevation portions of the basin." While mean leakage rates appear to be comparable to other basins in the United States, emissions in some parts of the San Juan Basin are essentially trapped due to topography. Noting that the background air quality in and near Durango, Colorado is likely being harmed by emissions from oil and gas operations in the San Juan Basin, these researchers cite the need for "rapid and deep" mitigation, with "much bolder emission cuts necessitating substantial and industry transformations" in order to meet global climate goals.[1699]

- October 15, 2020 – A team led by University of Wyoming researchers determined that methane emissions from oil and gas well pads in the western Permian Basin are 5.5-9.0 times greater the EPA has estimated. Using a mobile laboratory that collects ground-level data, researchers obtained measurements of methane 40-200 meters downwind of 71 oil and gas facilities in the Permian Basin of western Texas and southeastern New Mexico. Methane emissions in the Permian Basin had not previously been studied in ground-based fashion, and most of the basin is difficult to study with aerial approaches. Detailed analysis of the data revealed differences between "simple" sites, with no or minimal processing equipment and storage of liquids on-site, and "complex" sites that stored and processed liquids at or near the well pad. The emission profile of the simple sites was distinct, with far more simple sites registering methane levels below detection thresholds. Disaggregating these two types of sites in the data analysis can lead to greater accuracy in evaluating the high end of the emission distribution where complex sites account for 91 percent of total emissions and also allows for more meaningful statistical analysis, with better fit of data in commonly used probability plots. Total estimated emission rates for the New Mexico portion of the Permian Basin, as calculated by these methods, ranged from approximately 520,000 to 610,000 tons per year.[1700]

- September 19, 2020 – Researchers at the California Air Resources Board developed and deployed a novel measurement system for mobile sampling of methane emissions with the intent of identifying and fixing unexpected fugitive leaks. Measurements from a highly instrumented sport utility vehicle (the Mobile Measurement Platform) correlated with and extended inventory-based estimates when used for monitoring emissions at 86 natural gas well pads, including 20 idle well pads. Within approximately 100 meters downwind of emission sources, the system was able to detect low-level emissions, making the system potentially much easier to use than Optical Gas Imaging cameras, which require close proximity to a source (approximately 3-10 meters) for detection of

[1699] Gabrielle Pétron et al., "Investigating Large Methane Enhancements in the U.S. San Juan Basin," *Elementa Science of the Anthropocene* 8 (2020), https://doi.org/10.1525/elementa.038.
[1700] Anna M. Robertson et al., "New Mexico Permian Basin Measured Well Pad Methane Emissions Are a Factor of 5−9 Times Higher Than U.S. EPA Estimates," *Environmental Science & Technology* 54 (2020): 13926–34.

methane at similar and lower levels. The mobile system documented a highly skewed distribution. For active well pads, the top 10 percent of leaking wells were responsible for 80 percent of total emissions, and the top 20 percent were responsible for roughly 90 percent of total emissions. Findings for the idle well pads showed a similar distribution pattern but at much smaller magnitudes. These results demonstrate that using a mobile measuring system as a screening tool may lead to real-time detections of previously overlooked sources of large, potentially avoidable emissions of methane and "suggest that controlling a small number of large emitters can significantly reduce methane emissions."[1701]

- July 21, 2020 – A lawsuit brought by 15 states, spearheaded by Massachusetts and New York, led to the release of email messages that documents a successful, coordinated effort by oil and gas industry leaders to compel the White House to cancel nationwide methane reporting requirements. The suit alleges that the EPA engineered the repeal of the requirements without any internal analysis, illegally delaying the development of additional regulations to reduce methane emissions.[1702]

- July 15, 2020 – Continuing a "living review" of global methane emissions, an interdisciplinary consortium of scientists working under the rubric of the Global Carbon Project conducted a three-year update of their meta-analysis of data relevant to the global methane cycle. These data were gleaned from hundreds of individual studies. Incorporating regional atmospheric measurements, they calculated global methane emissions at 576 teragrams per year (range of 550-594), with 60 percent of global methane emissions coming from anthropogenic sources of all kinds. According to their analysis, mean annual emissions continue to rise with oil and gas production accounting for approximately 35 percent (range 30-42 percent) of total global anthropogenic emissions.[1703]

- July 14, 2020 − Stanford-led researchers estimated methane emissions by combining "top down" measurements of atmospheric methane emissions with a "bottom up" analysis of comprehensive global inventories to attribute emissions by sector. ("Top down" methods involve using aircraft to measure methane levels over an entire region. "Bottom up" approaches measure methane emissions on the ground from a representative sample of equipment.) They concluded that methane emissions reached a record high in 2017, the last year for which complete data are available.[1704] "Throughout the study period, agriculture [primarily cattle and sheep ranching] accounted for roughly two-thirds of all methane emissions related to human activities; fossil fuels contributed most of the

[1701] Xiaochi Zhou et al., "Mobile Sampling of Methane Emissions from Natural Gas Well Pads in California," *Atmospheric Environment* 244 (2021), https://doi.org/10.1016/j.atmosenv.2020.117930.
[1702] Lisa Friedman, "New Emails Show How Energy Industry Moved Fast to Undo Curbs," *The New York Times*, July 21, 2020, https://www.nytimes.com/2020/07/21/climate/trump-methane-climate-change.html?smid=tw-share.
[1703] Marielle Saunois et al., "The Global Methane Budget 2000–2017," *Earth System Science Data* 12, no. 3 (2020): 1561–1623, https://doi.org/10.5194/essd-12-1561-2020.
[1704] R. B. Jackson et al., "Increasing Anthropogenic Methane Emissions Arise Equally From Agricultural and Fossil Fuel Sources," *Environmental Research Letters* 15, no. 7 (2020), https://doi.org/10.1088/1748-9326/ab9ed2.

remaining third. However, those two sources have contributed in roughly equal measure to the increases seen since the early 2000s."[1705]

- July 12, 2020 – An investigation by Hiroko Tabuchi of the *New York Times* revealed that many oil and gas companies were hurtling toward bankruptcy, potentially leaving wells untended and leaking planet-warming methane, with the costs of clean up left to local communities. Rystad Energy, an analytics company, noted that almost 250 oil and gas companies could file for bankruptcy protection by the end of next year, more than the previous five years combined. As these businesses collapse, millions of dollars often flow to executive compensation.[1706]

- June 9, 2020 – Methane leaking from its natural gas infrastructure is increasing Israel's overall greenhouse gas emissions by eight percent and is threatening its international climate change commitments. The estimation of methane leakage addressed "the entire chain of production and distribution of Israel's Tamar and Leviathan gas wells, up to its arrival at gas-fired power stations." The more comprehensive national estimate reflects emissions that are routinely neither measured nor reported. Israel reported 7,000 tons of methane to the UN Framework Convention on Climate Change in 2018, but the report calculated that the Tamar and Leviathan wells 372,672.2 tons.[1707]

- May 13, 2020 – Pennsylvania gas drillers released more than 1.1 million tons of methane into 2017, 16 times the amount they reported to the state, according to an online report building on an earlier, peer-reviewed study. (See June 21, 2018 entry.) The updated data showed that fugitive emissions from fracked wells alone totaled 543,000 tons for 2017, not the 70,150 tons reported to the state Department of Environmental Protection (DEP). A similar amount was calculated from older, conventionally drilled wells, data that is not collected by the state. The total is more than 15 times higher than what oil and gas companies reported.[1708]

- May 1, 2020 – A helicopter survey of the Permian Basin employing infrared cameras found that 1 in 10 flares burning at oil and gas sites was unlit or malfunctioning and

[1705] Stanford's School of Earth, Energy & Environmental Sciences, "Global Methane Emissions Soar to Record High, Even As Pandemic Has Reduced Carbon Emissions," *Sci Tech Daily*, July 14, 2020, https://scitechdaily.com/global-methane-emissions-soar-to-record-high-even-as-pandemic-has-reduced-carbon-emissions/.

[1706] Hiroko Tabuchi, "Fracking Firms Fail, Rewarding Executives and Raising Climate Fears," *The New York Times*, July 12, 2020, https://www.nytimes.com/2020/07/12/climate/oil-fracking-bankruptcy-methane-executive-pay.html#:~:text=Fracking%20Firms%20Fail%2C%20Rewarding%20Executives%20and%20Raising%20Climate, methane%20%28which%20is%20invisible%20to%20the%20naked%20eye%29.

[1707] Sue Surkes, "Methane From Natural Gas Boosts Annual Global Warming Gases by 8% – Study," *The Times of Israel*, June 9, 2020, https://www.timesofisrael.com/methane-from-natural-gas-boosts-annual-global-warming-gases-by-8-study/.

[1708] Don Hopey, "Methane Leaks Much Worse than Previously Thought, Study Says," *Pittsburgh Post-Gazette*, May 13, 2020, https://www.post-gazette.com/news/environment/2020/05/13/Methane-leaks-much-worse-than-previously-thought/stories/202005120163.

venting methane gas straight into the atmosphere. These unlit flares may be responsible for more than 10 percent of the Permian's overall methane emissions.[1709]

- April 22, 2020 – Satellite analysis from a Harvard-led study using high-resolution instrumentation showed that methane is leaking from Permian Basin wells into the atmosphere at a rate of 3.7 percent.[1710, 1711] This leakage rate is approximately 60 percent higher than the national leakage rate of 2.3 ± 0.3 percent, a discrepancy that the authors attribute to the practice of extensive venting and flaring in the Permian oil fields. The Delaware sub-basin, part of the larger Permian, demonstrated an even higher rate than the average for the Basin, at 4.1 percent. Authors wrote, "with the rescinding of U.S. federal requirements on gas capture and fugitive emissions in 2018, current regulations on O/G methane emissions in the Permian Basin are less stringent at both federal and state levels… All these factors may increase the incentive for operators to vent and flare their product."

- April 17, 2020 – In 2020, the U.S. EPA began collecting emissions estimates from individual pieces of equipment, walking back an Obama-era method of estimating emissions drawn from "gathering stations," facilities that transport and control the flow of natural gas to processing plants and transmission pipelines. The new method can omit very large intermittent emissions and emissions from super-emitting sites. Environmental analysts contend that the new method may under-report methane emissions by as much as 40 percent. The old method reported 2.2 million metric tons of methane emissions in 2017, whereas the new method measured only 1.3 million metric tons of leaking methane even though production had increased.[1712]

- April 13, 2020 – Using technology previously used to detect methane emissions from land-based fossil fuel development, researchers found an "effective loss rate" of 2.9 percent over offshore oil and gas platforms in the Gulf of Mexico.[1713] Authors wrote that onshore methane emissions are large and often underestimated, while offshore methane emissions have not been closely examined. Gulf of Mexico drilling represented three percent of U.S. gas production in 2017. The study findings suggest the federal government's calculations of such emissions are too low, and "analogous to the highest emitting onshore basins." Large shallow-water central hub facilities are particularly likely to be related to "disproportionately high emission events."

[1709] Rachel Adams-Heard and Akshat Rathi, "When Flames Go Out, the Permian's Methane Problem Worsens," *Houston Chronicle*, May 1, 2020, https://www.houstonchronicle.com/business/energy/article/When-the-Flames-Go-Out-the-Permian-s-Methane-15239528.php.

[1710] Yuzhong Zhang et al., "Quantifying Methane Emissions From the Largest Oil-Producing Basin in the United States From Space," *Science Advances* 6, no. 17 (2020): eaaz5120, https://doi.org/10.1126/sciadv.aaz5120.

[1711] Adam Vaughan, "Fracking Wells In the US Are Leaking Loads of Planet-Warming Methane," *New Scientist*, April 22, 2020, sec. Environment, https://www.newscientist.com/article/2241347-fracking-wells-in-the-us-are-leaking-loads-of-planet-warming-methane/.

[1712] Stephen Lee, "EPA Estimate Undercounts Methane Emissions: Environmentalists," *Bloomberg Law*, April 17, 2020, https://news.bloomberglaw.com/environment-and-energy/epa-approach-undercounts-methane-emissions-environmentalists.

[1713] Alan M. Gorchov Negron et al., "Airborne Assessment of Methane Emissions from Offshore Platforms in the U.S. Gulf of Mexico," *Environmental Science & Technology* 54 (2020): 5112–20, https://doi.org/10.1021/acs.est.0c00179.

- April 9, 2020 – Using Pennsylvania's unique quarterly mechanical inspection reports, researchers determined that methane emissions from abandoned and active wells were at least 15 percent higher than previously thought.[1714] The researchers used 589,175 operator reports on methane leaks from both fracked and conventional oil and gas wells in the state from 2014 to 2018. The rate of flow of escaping methane from fracked wells (18.5 percent) was great than that from conventional wells. Extrapolating these findings to the nation as a whole, where over three million wells are in operation, shows that methane escaping from oil and gas wells undermine efforts to address climate change. "Another 15 percent of methane going into the atmosphere that we didn't know about is very significant for climate change in the short term," professor emeritus of engineering at Cornell and the study's lead author Anthony Ingraffea told *Environmental Health News*.[1715]

- April 7, 2020 – The International Energy Agency (IEA) cautioned that a sharp decline in oil and gas revenues during the pandemic may lead some companies to cut expenses by failing to fix leaks in gas pipes or cut losses by increasing the venting and flaring of unwanted gas. If so, atmospheric methane emissions may increase during the pandemic even as demand for natural gas falls off. A *Scientific American* report documents exactly this. The composition of greenhouse gases changed markedly the early months of 2020 and included a 10 percent reduction in carbon dioxide and a 50 percent reduction in carbon monoxide, as measured in New York City in March 2020 by researchers at Columbia University. In contrast to the carbon dioxide declines, attributable to the temporary slowdown in transportation and other industries, methane levels did not fall. However, lack of reliable data from global oil and gas producers, make the understanding of these trends difficult.[1716]

- April 6, 2020 –Since 1983, the National Oceanic and Atmospheric Administration's (NOAA) has tracked atmospheric methane levels through a globally distributed network of air sampling sites. In 2019, its Trends in Atmospheric Methane data project documented a dramatic leap in airborne methane levels.[1717] This project does not distinguish between the various natural and human-generated sources. However, commenting on the data, climate scientist Drew Shindell said, "The easiest way to stem methane pollution… is to limit its release from oil and gas drilling sites…. You see the benefits in the first decade or two that you make cuts. You see fewer people dying from

[1714] Anthony R. Ingraffea et al., "Reported Methane Emissions from Active Oil and Gas Wells in Pennsylvania, 2014–2018," *Environmental Science & Technology* 54, no. 9 (2020): 5783–89, https://doi.org/10.1021/acs.est.0c00863.
[1715] Kristina Marusic, "Oil and Gas Methane Emissions in US Are at Least 15% Higher than We Thought," *Environmental Health News*, April 23, 2020, https://www.ehn.org/fracking-methane-leaks-2645817287.html?rebelltitem=2#rebelltitem2.
[1716] John Fialka, "As CO2 Emissions Drop During Pandemic, Methane May Rise," *Scientific American*, April 7, 2020, https://www.scientificamerican.com/article/as-co2-emissions-drop-during-pandemic-methane-may-rise/.
[1717] E. Roston and N. S. Malik, "Methane Emissions Hit a New Record and Scientists Can't Say Why," *Bloomberg Green*, April 6, 2020, https://www.bloomberg.com/news/articles/2020-04-06/methane-emissions-hit-a-new-record-and-scientists-can-t-say-why.

heat waves. You see less powerful storms and all of the stuff that comes from climate change."[1718]

- March 31, 2020 – Pointing toward its online "Methane Tracker" as a tool to encourage both governments and the oil and gas industry to make proactive changes to reduce the emission of methane and other global greenhouse gases, the IEA highlighted the importance of new measuring capabilities provided by satellite and aircraft and the cost-effectiveness of reducing leakage during periods of reduced gas prices. The IEA wrote that methane trends held more uncertainty than carbon dioxide trends, and that "a drop in methane emissions from oil and gas cannot be taken for granted, even if oil and gas consumption falls." It is possible that a decline in revenues from oil and gas operations would lead to less effort to decrease emissions, and that low gas prices may lead to increases in flaring or venting.[1719]

- March 30, 2020 – Using an innovative, off-site approach, researchers mounted methane-measuring equipment on a nearby, downwind tower just prior to unconventional well drilling and fracturing. They documented large, frequent spikes of methane escaping from the observed well site, especially during the vertical drilling phase (316 percent greater amplitude than baseline) and the hydraulic stimulation phase (509 percent greater amplitude than baseline). Measurements of carbon-13 isotopes confirmed that the source of the methane emissions was geological. The researcher recommends this approach for passive, offsite measurement of methane leaks that can enable researchers and community members to obtain a clearer picture of the time-course of emissions at particular sites.[1720]

- March 6, 2020 – An international team of researchers used isotopic analysis and a published data set to assess what proportion of the ongoing global surge in atmospheric methane emissions is attributable to oil and gas extraction, especially from shale, as opposed to other sources of atmospheric methane, such as wetlands and cattle. They concluded that methane from shale gas and conventional natural gas do not greatly differ in their carbon-13 composition, suggesting that the isotopic signal now observable in the atmosphere is not consistent with that from fossil fuel-derived methane. This assessment contests Cornell University researcher Robert Howarth's earlier attribution of increasing global methane emissions to North American fracking operations, which is premised on the existence of an isotopic difference between shale gas and conventional gas caused by fractionation as methane slowly migrates from inside shale formations to conventional gas reserves. (See entry for August 14, 2019.) The authors stress nonetheless that "oil and

[1718] Jeremy Deaton, "Methane Levels Reach an All-Time High," *Scientific American*, April 12, 2020, https://www.scientificamerican.com/article/methane-levels-reach-an-all-time-high/.
[1719] Christophe McGlade, K. C. Michaels, and Tim Gould, "Global Methane Emissions From Oil and Gas: Insights From the Updated IEA Methane Tracker," *International Energy Agency*, March 31, 2020, https://www.iea.org/articles/global-methane-emissions-from-oil-and-gas.
[1720] Sarah J. Russell et al., "Quantifying CH4 Concentration Spikes Above Baseline and Attributing CH4 Sources to Hydraulic Fracturing Activities by Continuous Monitoring at an Off-Site Tower," *Atmospheric Environment* 228 (2020): 117452, https://doi.org/10.1016/j.atmosenv.2020.117452.

gas industry expansion remains a significant factor in the complex patterns of global atmospheric methane emissions and concentrations."[1721]

- February 29, 2020 – Annual emissions from fracking operations in Australia's Northern Territory could be as large as 22 percent of the nation's current annual emissions, according to government records obtained by the Australia Institute.[1722] Obtained under Freedom of Information procedures, the documents revealed that high production scenarios in the Territory would be "worse than the emissions of Australia's coal fleet across the National Energy Market (NEM) in 2030, and require more offsets each year than have ever been issued in Australia to date," threatening Australia's ability to meet international emissions reduction obligations. In the documents, government officials stated that emissions from fracking "could reach 39 million tonnes of carbon dioxide equivalent (MtCO2e) per year under one production scenario, and up to 117 MtCO2e per year under larger scale production."

- February 27, 2020 – Researchers at the International Institute for Applied Systems Analysis explored technical solutions for curbing methane emissions and transitioning to carbon-free energy alternatives and their costs. While technical solutions and alternative exist, adoption of new methods, policies, and approaches is only feasible through regulation or "if the future price of gas become[s] high enough to make gas recovery profitable." Specifically, extensive technical opportunities exist to control emissions "from waste and wastewater handling and from fossil fuel production and use."[1723]

- February 21, 2020 – Using measurements of carbon-14 and its isotopes from ice cores reflecting the most recent prior deglaciation period on earth (approximately 18,000 to 8,000 years before present), a team of researchers discovered that relatively little methane was emitted from "old carbon" sources, such as permafrost and methane hydrates under ice sheets.[1724] Instead, "old methane is often rapidly consumed by microorganisms living in sediments, soils, and water, which convert it to carbon dioxide before it can be released to the atmosphere."[1725] A similar pattern may hold as present global temperatures increase. Thus, the paper's lead author said, "we need to be more concerned about the anthropogenic emissions—those originating from human activities—than the natural feedbacks."[1726]

[1721] Alexei V. Milkov et al., "Using Global Isotopic Data to Constrain the Role of Shale Gas Production in Recent Increases In Atmospheric Methane," *Scientific Reports* 10 (2020): 4199, https://doi.org/10.1038/s41598-020-61035-w.
[1722] Tom Swann, "All It's Fracked Up to Be" (The Australia Institute, February 2020), https://australiainstitute.org.au/wp-content/uploads/2020/12/P875-All-its-Fracked-Up-to-Be-WEB.pdf.
[1723] Lena Höglund-Isaksson et al., "Technical Potentials and Costs for Reducing Global Anthropogenic Methane Emissions in the 2050 Timeframe –Results from the GAINS Model," *Environmental Research Communications* 2, no. 2 (2020): 025004, https://doi.org/10.1088/2515-7620/ab7457.
[1724] M. N. Dyonisius et al., "Old Carbon Reservoirs Were Not Important In the Deglacial Methane Budget," *Science* 367, no. 6480 (2020): 907–10, https://doi.org/10.1126/science.aax0504.
[1725] Joshua F. Dean, "Old Methane and Modern Climate Change," *Science* 367, no. 6480 (2020): 846–48, https://doi.org/10.1126/science.aba8518.
[1726] Lindsey Valich, "To Combat Climate Change, Human Activities More Important than Natural Feedbacks," *University of Rochester Newscenter*, February 21, 2020, https://www.rochester.edu/newscenter/combat-climate-change-human-activities-more-important-natural-feedbacks-416672/.

- February 19, 2020 – A University of Rochester-led team conducted an isotopic analysis of pre-industrial ice cores. The results showed that naturally occurring methane emissions from geological sources are relatively small (1.6 million tons per year) and contribute far less to global methane emissions than has been estimated (30 million to 60 million tons). Instead, human activities that liberate methane from geological formations—namely, fossil fuel extraction, distribution, and use—make a far greater contribution to global methane emissions and have heretofore been underestimated by 25 to 40 percent. Accordingly, reducing anthropogenic methane emissions is a firm target for mitigating climate change.[1727, 1728]

- February 12, 2020 – Researchers used drones to sample methane emissions downwind from a single fracking operation, demonstrating the utility of this method for a rapid response, highly precise, "snap shot" study in settings where access for other forms of monitoring may be restricted or where the study area is too small for satellite or high altitude aerial surveillance. High levels of methane emissions were correlated to venting at the fracking site. Such sampling can complement and supplement other methods for compiling inventories of methane emissions and can be used to study relative contributions to emissions of differing phases of fracking, including flow-back, venting, storage, and compression.[1729]

- February 3, 2020 – According to data available through the federal Energy Information Administration (EIA), flaring and venting of methane by the oil and gas industry increased in 2019 for a third year in a row. Compared to 20l8 levels, flaring and venting rose by seven percent in the Permian Basin underlying Texas and New Mexico, while the volumes of gas released or burned in North Dakota's huge Bakken oil field increased by 36 percent. Many states allow the practice, and few enforce regulations that are in place.[1730]

- January 28, 2020 – Researchers extended the use of the high-resolution, satellite-based instrumentation to measure methane emissions in multiple basins in the United States, including the Central Valley of California, the Uintah Basin in Utah, several basins in Texas, and a range of other states, including Florida. After corroborating their findings with findings from ground-based and airborne measurements, they suggest the possibility of greater accuracy, completeness, and utility through "future determination of regional

[1727] Benjamin Hmiel et al., "Preindustrial 14CH4 Indicates Greater Anthropogenic Fossil CH4 Emissions," *Nature* 578 (2020): 409–12, https://doi.org/10.1038/s41586-020-1991-8.
[1728] Warren Cornwall, "Humans Are a Bigger Source of Climate-Altering Methane, New Studies Suggest," *Science Magazine*, February 20, 2020, https://www.sciencemag.org/news/2020/02/only-humans-can-create-climate-altering-methane-burns-new-studies-suggest.
[1729] Adil Shah et al., "Unmanned Aerial Vehicle Observations of Cold Venting From Exploratory Hydraulic Fracturing in the United Kingdom," *Environmental Research Communications* 2, no. 2 (2020): 021003, https://doi.org/10.1088/2515-7620/ab716d.
[1730] Nichola Groom and Jennifer Hiller, "U.S. Oil Fields Flared and Vented More Natural Gas Again in 2019-Data," *Thomson Reuters Roundation News*, February 3, 2020, http://news.trust.org/item/20200203112531-yoq0j/.

methane emissions [via satellite] with a high time resolution and soon after the time of emission" in both the United States and internationally.[1731]

- January 11, 2020 – A report issued by New Mexico's Methane Advisory Panel, appointed by the Governor, suggests that methane venting and flaring have increased, despite conflicting claims from industry and declining numbers in EPA inventories, following changes in reporting methods. Compiling comments from multiple interested parties, "the report lays out comprehensive technical recommendations meant to guide environmental regulators as they craft a new methane rule involving everything from leaks in oil and gas storage tanks to pneumatic pumps."[1732]

- December 16, 2019 – Methane escapes from all parts of the extraction, distribution, and storage system for natural gas. Quantifying these emissions is difficult and yet dictates how quickly further investments in natural gas should end in order to meet greenhouse gas reduction targets. Researchers from the Massachusetts Institute of Technology calculated that reductions in leakage rates from natural gas infrastructure on the order of 30 to 90 percent would be required in order to meet proposed climate targets for 2030. The team projected out multiple scenarios to show the impact of differing approaches to reaching that goal, as well as the potential benefits and importance of identifying and targeting methane super-emitters. Given the difficulties of both measuring and mitigating methane emissions and given that virtually all scenarios for meeting greenhouse gas reduction targets call for ultimately phasing out natural gas by mid-century, further investments in natural gas infrastructure raise questions.[1733] "A certain amount of investment probably makes sense to improve and make use of current infrastructure, but if you're interested in really deep reduction targets, our results make it harder to make a case for that expansion right now," according to author Jessika Trancik.[1734]

- December 16, 2019 – Positing that lack of reliable measurements of accidental methane releases and intermittent emissions from high-volume point sources (super-emitters) in the oil and gas industry leads to omission of such data from emission inventories and reporting, researchers enlisted the use of a space-borne instrument to detail an extremely large methane plume observed in 2018, traceable to a natural gas well blowout in Ohio.[1735] Satellite records put the emission rate of the event in Ohio at 120 metric tons per hour, double the widely reported leak from the Aliso Canyon storage facility in

[1731] Joost A. de Gouw et al., "Daily Satellite Observations of Methane from Oil and Gas Production Regions in the United States," *Scientific Reports* 10 (2020): 1379, https://doi.org/10.1038/s41598-020-57678-4.
[1732] Michael Gerstein, "Report: Methane Venting, Flaring in Permian Doubled Since 2017," *Santa Fe New Mexican*, February 15, 2021, https://www.santafenewmexican.com/news/local_news/report-methane-venting-flaring-in-permian-doubled-since-2017/article_819dc5ac-3313-11ea-96ff-3f3802aff8b0.html.
[1733] Magdalena M. Klemun and Jessika Trancik, "Timelines for Mitigating the Methane Impacts of Using Natural Gas for Carbon Dioxide Abatement," *Environmental Research Letters* 14, no. 12 (2019): 124069, https://doi.org/10.1088/1748-9326/ab2577.
[1734] David L. Chandler, "The Uncertain Role of Natural Gas in the Transition to Clean Energy," *MIT News*, December 16, 2019, http://news.mit.edu/2019/role-natural-gas-transition-electricity-1216.
[1735] Sudhanshu Pandey et al., "Satellite Observations Reveal Extreme Methane Leakage From a Natural Gas Well Blowout," *Proceedings of the National Academy of Sciences* 116, no. 52 (2019): 26376–81, https://doi.org/10.1073/pnas.1908712116.

California in 2015, yet its full extent had gone undetected prior to investigation of the satellite's records, despite health complaints among residents closest to the well that included "throat irritation, dizziness, breathing problems."[1736] The extent of the methane released had also escaped the state's routine greenhouse gas accounting systems. Estimates of the total methane from the event, which lasted approximately 20 days, put that single source at roughly 60 kilotons of methane, equivalent to a quarter of Ohio's reported annual methane emissions and the total reported emissions of some countries. These results reinforce other recent findings that methane emissions from drilling and fracking operations are bigger and more problematic than previously assumed. The researchers urge the expanded use of such observations to identify methane hot spots in order to record these events and target them for intervention.

- December 10, 2019 – Thermal imaging equipment has allowed the nonprofit organization Earthworks to document billowing plumes of methane at oil and gas production sites in New Mexico, made visible through the infrared lens, according to the *Albuquerque Journal*.[1737] Clouds of gas emissions can signal open vents or malfunctioning equipment. Earthworks uses the information to seek reductions in emissions and, if necessary, reports emissions violations to the New Mexico Environment Department. Some measured emissions of methane in the Permian Basin in New Mexico are five times higher than EPA estimates. These findings have helped pushed Governor Michelle Lujan Grisham to pursue a first-of-its-kind state partnership with a commercial laboratory "to measure methane—accurately and in real time—using satellite tech and weather patterns."

- December 5, 2019 – After proclaiming publicly that Colorado would adopt aggressive climate goals, cut down on methane emissions through strict regulations, and keep pressure on the oil and gas industry for improved practices, elected officials were confronted with inaccuracies in the state-funded system to collect data and verify reductions in emissions. The state has declined to hire or to use data from other in-state sources such as aerial surveys by NOAA or private companies like Scientific Aviation, that can do precise real-time monitoring.[1738]

- December 4, 2019 – An international team of researchers examined the growing dependency on fossil fuels around the globe, "amidst declarations of planetary emergency and reports that the window for limiting climate change … is rapidly closing."[1739] They determined that the ongoing natural gas boom is serving a major barrier to rapid decarbonization. Natural gas is the fastest growing fossil fuel in the world. While it has

[1736] Hiroko Tabuchi, "A Methane Leak, Seen From Space, Proves to Be Far Larger Than Thought," *The New York Times*, December 16, 2019, sec. Climate Change, https://www.nytimes.com/2019/12/16/climate/methane-leak-satellite.html.
[1737] Theresa Davis, "Methane Emissions a Numbers Game in New Mexico," *Albuquerque Journal*, December 10, 2019, https://www.abqjournal.com/1399538/methane-emissions-a-numbers-game-in-new-mexico-ex-an-advisory-panel-will-discuss-what-regulations-would-be-practical-and-effective-for-the-state.html.
[1738] Grace Hood, "Colorado Talks A Mean Game On Methane. Bad Data, No Best Practices Say Otherwise," *Colorado Public Radio News*, December 5, 2019, https://www.cpr.org/2019/12/05/colorado-talks-a-mean-game-on-methane-bad-data-no-best-practices-say-otherwise/.
[1739] R. B. Jackson et al., "Persistant Fossil Fuel Growth Threatens the Paris Agreement and Planetary Health," *Environmental Research Letters* 14, no. 12 (2019): 121001, https://doi.org/10.1088/1748-9326/ab57b3.

indeed displaced coal—the use of coal in the United States has fallen by half over the past 15 years—the use of natural gas has soared so fast that the methane emissions from burning it have more than offset the decline in carbon dioxide emissions from the dwindling use of coal. The result is that carbon dioxide (or CO_2-equivalent) emissions from fossil fuels grew each year from 2017-2019. The low costs of natural gas, and new methods for transporting it, such as LNG tankers, are keeping the use of fossil fuels high even as renewable energy sources are also growing. As a result, the carbon intensity of global energy production has remained essentially unchanged since 1990. The study calls for "accelerated energy efficiency improvements and reduced consumption, rapid deployment of electric vehicles, carbon capture and storage technologies, and a decarbonized electricity grid, with new renewable capacities replacing fossil fuels," assisted by stronger global commitments and carbon pricing. "I have strong concerns about the pace of our natural gas build-out in the United States and globally because those facilities will be producing pollution for many decades," said lead author and Stanford University earth system scientist Rob Jackson.[1740]

- November 26, 2019 – Meteorologists used measurements from airborne instruments to model methane emissions across multiple oil and gas regions in Arkansas, Texas, Louisiana and Oklahoma that are estimated to contribute 40 percent of the oil and gas produced in the United States.[1741, 1742] These aerial data confirm other research showing that 1.1 to 2.5 times as much methane is being emitted by oil and gas activities than is estimated by inventories collected on the ground, such as those compiled by the EPA. Tracers, including ethane, allowed researchers to segregate methane emissions originating from the oil and gas sector from biogenic sources, such as livestock and manure. They also found that flying through massive methane plumes concentrated by regional weather front boundaries allowed them to measure methane emissions from a wide area.

- November 6, 2019 – Researchers employed the "Next Generation Airborne Visible/Infrared Imaging Spectrometer (AVIRIS-NG)" to detect, geolocate, and quantify point sources of less than 10 meters in diameter that emit methane, with a focus on identifying super-emitting landfills, livestock facilities, and oil and gas infrastructure. Their results allowed the team to estimate that the emissions from point sources were equivalent to 34-46 percent of the state's 2016 methane inventory. They also found super-emitters among every sector of point sources, with 10 percent of them accounting for roughly 60 percent of point-source emissions.[1743] Regular scans for such emissions

[1740] Nicholas Kusnetz, "Natural Gas Rush Drives a Global Rise in Fossil Fuel Emissions," *Inside Climate News*, December 4, 2019, sec. Fossil Fuels, https://insideclimatenews.org/news/03122019/fossil-fuel-emissions-2019-natural-gas-bridge-oil-coal-climate-change.
[1741] A. R. Barkley et al., "Forward Modeling and Optimization of Methane Emissions in the South Central United States Using Aircraft Transects Across Frontal Boundaries," *Journal of Geophysical Research: Atmospheres* 46, no. 22 (2019): 13564–73, https://doi.org/10.1029/2019GL084495.
[1742] David Kubarek, "Airborne Measurements Point to Low EPA Methane Estimates in South Central US," *Penn State News*, January 27, 2020, https://news.psu.edu/story/605629/2020/01/27/research/airborne-measurements-point-low-epa-methane-estimates-south-central.
[1743] Riley M. Duren et al., "California's Methane Super-Emitters," *Nature* 575 (2019): 180–84, https://doi.org/10.1038/s41586-019-1720-3.

are needed, especially since sharing data about these localized "puffs" of methane with collaborating infrastructure operators in some cases led to mitigation.[1744]

- October 25, 2019 – High-resolution satellite instrumentation detected an unexpectedly large, persistent methane source in Central Asia, along with additional nearby sources of high emission.[1745] The amount of methane detected equaled the "total emissions from the Aliso Canyon disaster—the largest accidental release of greenhouse gases in U.S. history."[1746] While the exact cause of the emissions cannot be determined, venting (blowdowns) from a gas compressor station or malfunction of a valve on a pipeline seem likely. The researchers compared and confirmed their results with observations from another satellite based measuring instrument. The results point toward a potential strategy for monitoring in which "instruments with global coverage at coarse spatial resolution can first identify methane hot spots and then instruments with fine spatial resolution but limited coverage can zoom in to identify the facilities responsible for the hot spots."

- October 16, 2019 – Despite pledges from oil and gas industry executives to curb the energy-wasting practice of flaring off excess natural gas, rates of flaring have significantly increased in recent years, along with rates of venting unburned gas. In 2018, operators across three basins (the Eagle Ford and Permian basins in the Southwest and the Bakken Formation at the Canadian border) flared or vented a record 320 million cubic feet of gas, more than 40 percent above levels seen just five years ago. Oil producers often treat natural gas as a liability, flaring it rather than paying to pipe it away for sale. "Last year in Texas, venting and flaring in the Permian Basin oil field alone consumed more natural gas than states like Arizona and South Carolina use in a year."[1747]

- August 14, 2019 –Isotopic analysis can distinguish methane produced from microbes (biogenic methane) from methane emissions arising from oil and gas operations (thermogenic methane). During the final 20 years of the 20th century, as atmospheric methane concentrations rose, isotopic analysis allowed scientists to conclude that fossil fuels and not microbes were driving the increase. During a second methane surge, beginning in 2009, the isotopic evidence led some researchers to conclude that biogenic sources, such as tropical wetlands, rice culture, or animal agriculture were the most likely driver of the observed methane increases. (See entry for March 10, 2016.) However, Cornell University biogeochemist Robert Howarth proposes an alternative view, noting that previous studies did not explicitly consider shale gas, which has a lighter isotopic signature that more closely resembles that of microbial methane. Correcting the earlier analyses for this difference, Howarth concluded that shale gas production in North

[1744] Leslie Nemo, "'Super-Emitters' In California Release A Third Of The State's Methane," *Discover*, November 5, 2019, https://www.discovermagazine.com/environment/super-emitters-in-california-release-a-third-of-the-states-methane.
[1745] D. J. Varon et al., "Satellite Discovery of Anomalously Large Methane Point Sources From Oil/Gas Production," *Geophysical Research Letters* 46, no. 22 (2019): 13507–16, https://doi.org/10.1029/2019GL083798.
[1746] Carlos Anchondo, "Satellite Discovers 'Anomalously Large' Methane Plume," *E&E News*, November 26, 2019, https://web.archive.org/web/20191128174408/https://www.eenews.net/energywire/stories/1061647835.
[1747] Hiroko Tabuchi, "Despite Their Promises, Giant Energy Companies Burn Away Vast Amounts of Natural Gas," *The New York Times*, October 16, 2019, https://www.nytimes.com/2019/10/16/climate/natural-gas-flaring-exxon-bp.html.

America over the past decade may have contributed "more than half of all of the increased emissions from fossil fuels globally and approximately one-third of the total increased emissions from all sources globally over the past decade." In other words, the North American fracking boom is globally important in the current rise in global methane levels and "may well be the leading cause of the increased flux."[1748] Stabilizing the climate by slashing methane emissions from the extraction, transport, storage, processing, and use of fossil fuels—particularly those obtained via fracking—is "the low-hanging fruit to slow global warming."[1749] (See also entry for March 6, 2020 above.)

- July 29, 2019 – To measure fugitive methane emissions from urban areas and identify the sources of those emissions, scientists used atmospheric observations of methane, carbon dioxide, carbon monoxide, and ethane downwind from six "old and leak-prone major cities" along the northeast coast of the United States. Their findings showed that these regions are leaking twice as much methane as indicated in EPA inventories. This discrepancy is possibly due to underestimates of natural gas leakage from urban distribution sources or from lack of inclusion of end-use emissions, or both.[1750] The amount of methane emitted by these six cities is large ("well over triple the amount emitted by gas production in the Bakken shale formation in the U.S. Midwest") and preventable. Possible sources of the leaks include natural gas pipelines, pumps, valves, water treatment systems, gas-fired power plants, and leaks from within homes and businesses.[1751]

- July 15, 2019 – Measurements of methane from a remote sensing spectrometer located just outside Los Angeles documented a correlation between methane levels and consumption of natural gas by residential and commercial consumers in the city, with measured emissions more than twice the level of estimates derived from monitoring equipment on the ground. If a causal correlation exists between the greater amount of gas burned in cold weather and higher methane levels, then the study estimates that about 1.4 percent of the commercial and residential natural gas consumption in Los Angeles is released into the atmosphere.[1752] To meet mandated reductions in emissions in California, sources of emission must be identified and quantified—in this case, the entire urban distribution system, "from storage fields to pipelines to stoves and furnaces."[1753] This

[1748] Robert W. Howarth, "Ideas and Perspectives: Is Shale Gas a Major Driver of Recent Increase in Global Atmospheric Methane?," *Biogeosciences* 16 (2019): 3033–46, https://doi.org/10.5194/bg-16-3033-2019.
[1749] Ruth Schuster, "As Fracking Poisons the Air, Israeli Scientists Propose to Engineer Cows," *Haaretz*, August 14, 2019, sec. Science & Health, https://www.haaretz.com/science-and-health/as-fracking-poisons-the-air-israeli-scientists-propose-to-engineer-cows-1.7683463.
[1750] Genevieve Plant et al., "Large Fugitive Methane Emissions From Urban Centers Along the U.S. East Coast," *Geophysical Research Letters* 46, no. 14 (2019): 8500–8507, https://doi.org/10.1029/2019GL082635.
[1751] Sid Perkins, "Major U.S. Cities Are Leaking Methane at Twice the Rate Previously Believed," *Science*, July 19, 2019, https://www.sciencemag.org/news/2019/07/major-us-cities-are-leaking-methane-twice-rate-previously-believed.
[1752] Liyin He et al., "Atmospheric Methane Emissions Correlate With Natural Gas Consumption From Residential and Commercial Sectors in Los Angeles," *Geophysical Research Letters* 46, no. 14 (2019): 8563–71, https://doi.org/10.1029/2019GL083400.
[1753] Emily Velasco, "Natural-Gas Leaks Are Important Source of Greenhouse Gas Emissions in Los Angeles," *Caltech News*, August 12, 2019, https://www.caltech.edu/about/news/natural-gas-leaks-are-important-source-greenhouse-gas-emissions-los-angeles.

approach provides a simple and relatively inexpensive method to address an often-overlooked component of global methane pollution.

- July 2, 2019 – Venting and flaring events at fracking sites release not only the greenhouse gases carbon dioxide and methane but also toxic air pollutants, including hydrogen sulfide, formaldehyde, sulfur dioxide, benzene, and volatile aromatic hydrocarbons. These events are self-reported by the industry to state agencies. Because there is almost no independent auditing, the precision and accuracy of self-reported venting and flaring volumes remain unknown. A research team from Texas A&M working in the Permian and Eagle Ford basins therefore created and attempted to match detailed maps of flared gas from both self-reported data collected on-site by the operators and satellite aerial data. Their results revealed that flaring volumes measured by satellite were at least two time greater than self-reported volumes submitted by the operators to the state. The authors note that venting and flaring reports are not mandated until after the well is drilled, fracked, and hooked up to the pipeline and also enjoy other exemptions. "Self-reported volumes significantly underestimate the volume of gas being vented or flared."[1754]

- June 7, 2019 – In a perspective published in *Science*, researchers from the National Institute of Water and Atmospheric Research in New Zealand considered the climate risks posed by rising global methane levels and their possible sources. In 2007, after a seven-year period of no change, the amount of methane in the atmosphere began to rise. The rate of increase then doubled from 2014 to the end of 2018, threatening to undermine the goals to limit planetary temperature increases, as set out in the Paris Agreement. The cause of this ongoing methane surge has four possible explanations, according to the authors: fossil fuel sources, biogenic sources, especially ruminant livestock; methane release from wetlands, particularly in the southern tropics, triggered by rising global temperatures; or a decline in the atmosphere's ability to break methane molecules apart, slowing the natural decay rate of methane.[1755]

- May 27, 2019 – In response to discussions about possible future fracking activities in Germany and the United Kingdom, researchers at the Institute for Advanced Sustainability Studies in Germany developed projections for emissions of greenhouse gases and associated local air pollutants, with a realistic scenario assuming "business-as-usual" activities and an optimistic scenario based on "the lowest emissions technically possible" including "full compliance with a stringent regulatory framework…."[1756] In addition to other harmful effects from fracking activities such as earthquakes and surface and groundwater contamination, projections of atmospheric impacts from drilling 480 wells annually in the two countries suggest that methane and carbon dioxide emissions

[1754] Katherine Ann Willyard and Gunnar W. Schade, "Flaring in Two Texas Shale Areas: Comparison of Bottom-Up With Top-Down Volume Estimates for 2012 to 2015," *Science of the Total Environment* 691 (2019): 243–51, https://doi.org/10.1016/j.scitotenv.2019.06.465.
[1755] Sara E. Mikaloff Fletcher and Hinrich Schaefer, "Rising Methane: A New Climate Challenge," *Science* 364, no. 6444 (2019): 932–33, https://doi.org/10.1126/science.aax1828.
[1756] Lorenzo Cremonese et al., "Emission Scenarios of a Potential Shale Gas Industry in Germany and the United Kingdom," *Elementa: Science of the Anthropocene* 7, no. 18 (2019), https://doi.org/10.1525/elementa.359.

with fracking are considerably higher than with conventional oil and gas production under the realistic scenario, with leakage rates only meeting current government figures under the 'optimistic' scenario, which the researchers acknowledge is "rather unlikely to be systematically employed or achieved." One of the reviewers suggested that "In light of the climate crisis, the environmental risks posed by gas emissions need to move quickly onto the agenda in policy making and in negotiations with the gas industry in order to keep the adverse effects of a European shale gas industry to an absolute minimum."[1757]

- March 12, 2019 – Using aircraft, a team of researchers from multiple universities and institutions estimated emissions from both coal mines and shale gas wells in southwestern Pennsylvania. For coal, their results largely aligned with EPA estimates. However, for natural gas wells, emissions were five times higher than EPA figures. Because the volume of gas extracted per well is higher than in other shale basins, production-scaled methane emissions were still comparatively low, with carbon dioxide emissions from combustion remaining the dominant source of greenhouse gas emissions.[1758]

- March 7, 2019 – Methane is a very strong greenhouse gas, with 120 times the power to trap heat than an equivalent amount of carbon dioxide. However, methane persists in the atmosphere for an average of only 12.4 years whereas carbon dioxide can linger for a century or more. Using a combination of approaches, a London team assessed the contribution of natural gas extraction to future greenhouse gas emissions in the United States, taking into account timing as well as magnitude of emissions and changing prices. They found that methane emitted further into the future—and therefore closer to the year where climate stabilization needs to take place—has a disproportionately large bearing on the overall climate impact of drilling and fracking activities, with long-lived gas fields having the most effect. "A key finding of this study is that the environmental and economic consequences of emissions are likely to rise with the age of a field, thus exposing long-lived assets to the greatest potential losses….Overall, our results suggest that future cumulative greenhouse gas emissions from existing US [gas] fields have a significant short-medium climate impact." The authors recommend carbon pricing as a strategy to shorten the lifetime of long-lived gas fields. They also report that 40 percent of carbon dioxide output from natural gas is directly related to drilling activities.[1759]

- February 28, 2019 – Australia's LNG export industry contributed significantly to rising carbon emissions from that country in the 12 months prior to September 2018, according to Australia's National Greenhouse Gas Inventory. Emissions from power plants fell during this same time period as the result of a 31 percent jump in renewable energy serving eastern Australia. These declines, however, were more than offset by soaring

[1757] Rachel Cordery, "Shale Gas Fracking Could Increase Emissions," *Power Technology*, July 25, 2019, sec. News, https://www.power-technology.com/news/shale-gas-increases-harmful-emissions/.
[1758] Z. R. Barkley et al., "Estimating Methane Emissions From Underground Coal and Natural Gas Production in Southwestern Pennsylvania," *Geophysical Research Letters* 46, no. 8 (2019): 4531–40, https://doi.org/10.1029/2019GL082131.
[1759] Daniel J. G. Crow et al., "Assessing the Impact of Future Greenhouse Gas Emissions From Natural Gas Production," *Science of the Total Environment* 668 (2019): 1242–58, https://doi.org/10.1016/j.scitotenv.2019.03.048.

increases in industrial and fugitive emissions from Australia's LNG plants.[1760] LNG exports rose by one fifth in 2018.[1761] This jump represents the third consecutive year of rising greenhouse gas emissions from Australia. The expansion in LNG production and export was identified as the major contributor to this trend.[1762]

- February 27, 2019 – An international team investigated the climate and the public health harms attributable to fossil fuel combustion. Their global model estimated an avoidable excess mortality rate of 3.61 million deaths per year from air pollution alone. Air pollution also chemically reacts with dust to create aerosols that disrupt the hydrologic cycle and impede rainfall patterns. If fossil fuel burning ended, not only would deaths due to air pollution be avoided but additional lives would be saved as water and food security improved in densely populated areas of India, northern China, and central America. In sum, "a rapid phaseout of fossil fuel-related emissions and major reductions of other anthropogenic sources are needed to save millions of lives, restore aerosol-perturbed rainfall patterns, and limit global warming to 2 C°."[1763]

- February 12, 2019 – In southeastern Saskatchewan, Canada, conventional gas and oil drilling takes place side by side with unconventional drilling via fracking. In a first study of its kind, a St. Francis Xavier University research team directly compared methane emissions from both types of co-located wells. By conducting truck-based air sampling downwind from 645 conventional wells and 289 unconventional wells, the team found that 28 percent of conventional wells leaked methane compared to 32 percent of fracked wells. The bigger difference was in measures of mean emission intensities from the wells that were leaking. Leaking fracked wells emitted nearly three times as much methane (59 cubic meters of methane per day) as leaking conventional wells (20 cubic meters of methane per day). "Our results showed that unconventional sites in southeastern Saskatchewan emit about as often as nearby conventional sites, but with somewhat greater severity."[1764]

- February 5, 2019 – A team led by University of Maryland researchers conducted aircraft sampling in 2015 to assess leakage from drilling and fracking operations in the southwestern Marcellus Shale. Coalbeds were the likely source of more than 70 percent of the emitted methane. Of the methane that likely arose from shale gas wells, the estimated mean emission rate was 1.1 percent of the total natural gas extraction. These

[1760] Commonwealth of Australia Department of Environment and Energy, "Quarterly Update of Australia's National Greenhouse Gas Inventory for September 2018," 2018, https://www.industry.gov.au/data-and-publications/national-greenhouse-gas-inventory-for-september-2018.
[1761] Peter Hannam, "Annual Emissions Keep Rising as Gas Jump Counters Power Sector Drop," *The Sydney Morning Herald*, February 28, 2019, sec. Climage Change, https://www.smh.com.au/environment/climate-change/annual-emissions-keep-rising-as-gas-jump-counters-power-sector-drop-20190228-p510wu.html.
[1762] Lisa Cox, "Gas Boom Fuels Australia's Third Straight Year of Rising Emissions," *The Guardian*, May 14, 2018, https://www.theguardian.com/environment/2018/may/14/gas-fuels-australias-third-straight-year-of-rising-emissions.
[1763] J. Lelieveld et al., "Effects of Fossil Fuel and Total Anthropogenic Emission Removal on Public Health and Climate," *Proceedings of the National Academy of Sciences U.S.A.* 116, no. 5 (2019): 7192–97, https://doi.org/10.1073/pnas.1819989116.
[1764] Jennifer Baillie et al., "Methane Emissions From Conventional and Unconventional Oil and Gas Production Sites in Southeastern Saskatchewan, Canada," *Environmental Research Communications* 1, no. 1 (2019): 011003, https://doi.org/1088/2515-7620/ab01f2.

results were consistent with (but at the low end of) estimates determined by previous observational studies in this region. They indicate that the climate impact of natural gas combustion falls below that of coal. Nevertheless, the full range includes values up to 3.5 percent, which falls above the break-even point with coal over a 20-year time span.[1765]

- February 5, 2019 – Sampling air from remote locations all over the world, an international team of atmospheric scientists confirmed a sharp rise in global atmospheric methane. This spike began in 2007 and has accelerated since 2014. The causes for the increase are not fully understood. The research team also documented, over the same time period, a shift in the carbon isotope ratio, which may signal a shift in the relative proportions of emissions from different sources. (These various methane sources include, for example, gas leaks, microbes, livestock, landfills, biomass burning.) Alternatively—or additionally—it may signal a decline in the oxidative capacity of the atmosphere, which breaks apart methane molecules. A change in the rate of methane destruction can also change the carbon isotope ratio. Either way, a sharp, ongoing increase in global methane concentrations was not predicted by the future greenhouse gas scenarios that were incorporated into the targets of the Paris Agreement. If the current increase continues, the goals of that treaty could be out of reach. "There is now urgent need to reduce methane emissions, especially from the fossil fuel industry… anthropogenic methane emissions are relatively very large and thus offer attractive targets for rapid reduction, which are essential if the Paris Agreement aims are to be attained."[1766]

- February 4, 2019 – Permafrost is soil that remains frozen year-round. If it thaws, microbes turn the carbon contained in the soil into carbon dioxide and methane. Because such a vast amount of carbon is held in permafrost, warming Arctic temperatures may release a large pulse of climate-destabilizing methane and so trigger an uncontrolled positive feedback loop. A study by an international team looked at the fate of permafrost under different scenarios of greenhouse gas mitigation, including some in which no progress is made toward decreasing fossil fuel-based emissions and others in which the targets of the Paris Agreement are met. In their analysis, the team determined the highest level of natural methane emissions that can be released from the Arctic by 2100. This level is considerably lower than likely anthropogenic methane emission levels over the same time period, which indicates that human-made emissions can be reduced sufficiently to limit methane-causing climate warming by 2100 even if the permafrost undergoes an uncontrolled emission feedback—but only if a committed, global effort to reduce fossil fuel use takes place very soon.[1767] In a press release about this research, one of the authors of the study, Lena Högland-Isaksson, said, "It is important to put the two estimates alongside each other to point out how important it is to urgently address methane emissions from human activities, in particular through a phase out of fossil

[1765] Xinrong Ren et al., "Methane Emissions From the Marcellus Shale in Southwestern Pennsylvania and Northern West Virginia Based on Airborne Measurements," *Journal of Geophysical Research: Atmospheres* 124 (2019): 1862–78, https://doi.org/10.1029/2018JD029690.
[1766] E. G. Nisbet et al., "Very Strong Atmospheric Methane Growth in the 4 Years 2014–2017: Implications for the Paris Agreement," *Global Biogeochemical Cycles* 33, no. 3 (2019): 318–42, https://doi.org/10.1029/2018GB006009.
[1767] Torben Røjle Christensen et al., "Tracing the Climate Signal: Mitigation of Anthropogenic Methane Emissions Can Outweigh a Large Arctic Natural Emission Increase," *Scientific Reports* 9 (2019): 1146, https://doi.org/10.1038/s41598-018-37719-9.

fuels. It is important for everyone concerned about global warming to know that humans are the main source of methane emissions and that if we can control humans' release of methane, the problem of methane release from the thawing Arctic tundra is likely to remain manageable."[1768]

- December 4, 2018 – Research firm Rystad Energy reported that gas flaring in the west Texas Permian Basin has doubled since 2017. Oil wells in the region pump out large volumes of associated natural gas. Without pipelines to bring the gas to burner tips, and in order to maintain the rapid pace of oil drilling, operators simply waste the gas—worth more than $1 million per day—by burning it off in flare stacks. Flaring permits are limited to 45 days but are now routinely extended for up to six continuous months.[1769]

- November 23, 2018 – In a report commissioned by the Obama administration in 2016, the U.S. Geological Survey (USGS) provided estimates on greenhouse gas emissions associated with the extraction and combustion of fossil fuels produced from federal lands. Between 2005 and 2014, fully one-quarter of all U.S. carbon emissions come from fossil fuels that were extracted from public lands. The report found that forests on federal lands can offset some of these emissions but only by 15 percent. Fossil fuels are extracted from public lands in 28 states with more than half the total carbon emissions coming from Wyoming.[1770, 1771]

- October 29, 2018 – The Basin Methane Reconciliation Study was a large-scale field investigation that brought together more than 80 scientists from multiple institutions. They examined why different methods of accounting for methane emissions from natural gas drilling sites vary so widely across the United States. The study took place in 2015 in Arkansas' Arkoma Basin and utilized both bottom-up and top-down approaches, which is to say, measurements were taken on the ground at selected facilities as well as in the atmosphere over the region, via aircraft. This type of concurrent dual analysis had never been attempted before. The study revealed spikes of high emissions that occur during daytime maintenance operations, as when, for example, liquids are being removed from a well and natural gas is freely vented into the air for the duration of that process. The high temporal variability and episodic nature of methane emissions likely explain the persistent gap between the two accounting methods and mean that researchers who attempt to determine how much methane is escaping from drilling and fracking operations require "detailed activity data, unfettered and unbiased site access, and time-resolved operations data." This type of study necessarily requires cooperation with

[1768] International Institute for Applied Systems Analysis, "Diffusing the Methane Bomb: We Can Still Make a Difference," Press Release, February 6, 2019, https://www.sciencedaily.com/releases/2019/02/190206104538.htm.
[1769] Jordan Blum, "Permian Basin Gas Flaring Has Nearly Doubled In a Year," *Houston Chronicle*, December 4, 2018, sec. Energy, https://www.houstonchronicle.com/business/energy/article/Record-Permian-gas-flaring-has-nearly-doubled-in-13443024.php.
[1770] Matthew D. Merrill et al., "Federal Lands Greenhouse Gas Emissions and Sequestration in the United States: Estimates for 2005–14," *U.S. Geological Survey Scientific Investigations Report 2018-5131*, 2018, https://doi.org/10.3133/sir20185131.
[1771] Adam Aton, "Fossil Fuel Extraction on Public Lands Produces One Quarter of U.S. Emissions," *E&E News*, November 27, 2018, https://www.scientificamerican.com/article/fossil-fuel-extraction-on-public-lands-produces-one-quarter-of-u-s-emissions/.

industry employees.[1772]

- August 1, 2018 – The Groningen natural gas field in the northern Netherlands is one of Europe's major gas fields where extraction, gas processing, and gas storage all take place. It is also a region with intensive agriculture and cattle operations. An international research team investigated methane emissions there with the intent of distinguishing between methane from fossil fuel sources and methane arising from livestock, wetlands, and agriculture. Using both ground and aircraft measurements, the researchers determined that emissions from oil and gas operations account for 20 percent of regional methane, with the remainder from biogenic sources. That figure for fossil fuel sources is, nevertheless, ten times higher than the 1.9 percent that was estimated by previous inventories. Ground-based measurements at extraction, processing, and storage sites found low emission rates compared to gas production facilities in the United States. Production volume was a poor predictor of emission rates. Even wells with no production still had emissions.[1773]

- August 1, 2018 – California's climate goals call for an 80 percent reduction in emissions by 2050. With this goal in mind, a Lawrence Berkeley National Laboratory team set out to estimate what fraction of California's greenhouse gas emissions represent methane emissions from residential homes, including leakage from gas pipes, stovetops, combustion appliance pilot lights, and forced air furnaces. Total methane emissions from California homes represent 15 percent of the total emissions from the natural gas sector in California and represent two percent of the state's total methane emissions, as calculated in the 2015 state inventory. The team also found that emissions from pilot lights constitute a significant fraction as do flames in domestic hot water heaters. "While methane emissions from houses are small compared to most sources, California's ambitious goals…suggest value in testing and repairing obvious leaks in residential gas lines, modernizing combustion appliances to move away from pilot lights, and gradually increasing the use of non-fossil fuel energy sources for residential space and hot water heating and cooking."[1774]

- July 10, 2018 – In 2015, as part of a follow-up study, a research team used helicopters to measure methane emission patterns at 353 well pads in North Dakota's Bakken Shale that had been surveyed in the same way in 2014. In the interim, 21 newly producing well pads were added to the sampling area. They found that the individual well pads that emitted methane in 2014 were far more likely to be still emitting in 2015 than would be expected by chance alone. The reasons for this persistent leaking were not identified but potentially include tanks without vapor recovery systems, overpressurization, undersized flaring systems, stuck or clogged valves, and "poorly designed equipment." Altogether,

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[1772] Timothy L. Vaughn et al., "Temporar Variability Largely Explains Top-Down/Bottom-Up Difference in Methane Emission Estimates From a Natural Gas Production Region," *Proceedings of the National Academy of Sciences U.S.A.* 115, no. 46 (2018): 11712–17, https://doi.org/10.1073/pnas.1805687115.
[1773] Tara I. Yacovitch et al., "Methane Emissions in the Netherlands: The Groningen Field," *Elementa Science of the Anthropocene* 6, no. 57 (2018), https://doi.org/10.1525/elementa.308.
[1774] Marc L. Fischer et al., "Natural Gas Methane Emissions From California Homes" (California Energy Commission, 2018), https://www.energy.ca.gov/publications/2018/natural-gas-methane-emissions-california-homes.

researchers quantified 33 plumes of methane and ethane arising from these well pads.[1775]

- June 21, 2018 – An analysis of methane leaks from the U.S. oil and gas supply chain found that natural gas is just as damaging as coal for the climate over a 20-year time frame. This study combined on-the-ground measurements of leaks at selected facilities (bottom-up methods) with data collected from the atmosphere via aircraft (top-down methods). Based on the results, the authors estimated that roughly 2.3 percent of all the natural gas extracted in the United States escapes into the air. This estimated level of leakage was 60 percent higher than the EPA's estimate of 1.4 percent. The authors believe their emissions estimate is the more accurate because they used helicopters to capture episodic releases of large plumes of methane caused by "abnormal operating conditions" and "failure-prone systems" that were likely missed by the sampling methods used for EPA's greenhouse gas inventory. Liquid storage tank hatches and vents were the source of most of acute incidents.[1776]

- December 20, 2017 – A major study led by NASA researchers concluded. that fossil fuel sources are driving the sharp uptick in global atmospheric concentrations of methane since 2006. Using satellite measurements and isotopic analysis, the team showed that methane from biomass sources, such as fires, decreased over the time period 2001-2016 while fossil fuel sources of methane increased. These findings helped reconcile conflicting results from other previous studies.[1777]

- October 17, 2017 – Using planes, an international team of researchers measured regional airborne methane and ethane emission rates from the Alberta oil and gas fields in Canada. They compared these results to emissions reported by the industries themselves, as part of an accounting system that requires operators to report flaring and venting volumes, and found large discrepancies. Based on the amounts of methane and ethane detected in the atmosphere above the oil and gas fields, the reported industry emissions in this region should be 2.5 ± 0.5 times higher. Such large discrepancies between actual methane emissions and industry-provided data represent a "reporting gap" and present a critical challenge when determining policy. Proposed regulations in Canada currently call for reducing methane emissions from Canadian fracking operations by 45 percent. However, these data indicate that most of the methane emissions from these operations arise from fugitive leaks that are not being measured at all and/or from episodes of unreported venting.[1778]

[1775] Jacob G. Englander et al., "Aerial Interyear Comparison and Quantification of Methane Emissions Persistence in the Bakken Formation of North Dakota, USA," *Environmental Science & Technology* 52, no. 15 (2018): 8947–53, https://doi.org/10.1021/acs.est.8b01665.
[1776] Ramon A. Alvarez et al., "Assessment of Methane Emissions From the U.S. Oil and Gas Supply Chain," *Science* 361, no. 6398 (2018): 186–88, https://doi.org/10.1126/science.aar7204.
[1777] John R. Worden et al., "Reduced Biomass Burning Emissions Reconcile Conflicting Estimates of the Post-2006 Atmospheric Methane Budget," *Nature Communications* 8 (2017): 2227, https://doi.org/10.1038/s41467-017-02246-0.
[1778] Matthew R. Johnson et al., "Comparisons of Airborne Measurements and Inventory Estimates of Methane Emissions in the Alberta Upstream Oil and Gas Sector," *Environmental Science & Technology* 51, no. 21 (2017): 13008–17, https://doi.org/10.1021/acs.est.7b03525.

- July 18, 2017 – A team of 15 climate scientists led by James Hansen at Columbia University conducted a study on the growth rate of greenhouse gas climate forcing, which has accelerated by 20 percent in the past decade. (Climate forcing is the difference between the amount of the sun's energy that is absorbed by the Earth and amount that radiates back into space.) The authors note that methane (CH_4) is the largest climate-forcing gas after carbon dioxide. With an atmospheric lifetime of only about ten years, "there is potential to reduce climate forcing rapidly if CH_4 sources are reduced." However, "there is a danger of increased leakage with expanded shale gas extraction." Noting that the speed of ice sheet melting and sea level rise are difficult to predict, the authors assert that targets for limiting global warming should aim to keep global temperatures close to the preindustrial Holocene range rather than allow them to rise to those found during the prior Eemian period, when sea levels were 6-9 meters higher than today. Such targets require immediate phase-out of fossil fuel emissions, along with profound changes in farming and forestry practices. A delay in taking these measures to minimize irreversible climate impacts means that the next generation will be required to undertake risky, expensive, large-scale CO_2 extraction practices, such as carbon capture. "If high fossil fuel emissions continue, a great burden will be placed on the young. . . . Continued high fossil fuel emissions unarguably sentences young people to either a massive, implausible cleanup or growing deleterious climate impacts or both."[1779]

- July 8, 2017 – An investigative report from the Inter Press Service News Agency examined the climate impacts of methane emissions from Mexico, which is sixth among the world's nations in technically recoverable shale gas reserves (after China, Argentina, Algeria, the United States, and Canada). Mexico's current energy policy, introduced in 2014, emphasizes the exploitation of shale gas using fracking. Using data from the state-owned energy company Petroleos Mexicanos (PEMEX), the Inter Press Service story documents that as of 2017, more than 900 wells, located in six of Mexico's 32 states, have been drilled and fracked. High volumes of methane are emitted during venting, and methane emissions have been increasing sharply. In 2016, the total methane emissions from Mexico's PEMEX Exploration and Production operations were 641,517 metric tons, 38 percent higher than the previous year. According to researcher Ramón Torres, of the National Autonomous University of Mexico, who is quoted in the story, "Current regulations are based on best practices, but the philosophy of environmental protection has been abandoned. Exploitation is deepening inequities in a negative way, such as environmental impact. It is irresponsible to auction reserves without a proper evaluation of environmental and social impacts."[1780]

- June 19, 2017 – A study that measured methane emissions from various components of drilling and fracking equipment on well pads located in four different shale basins in Colorado, Utah, Arkansas, and Wyoming found widely varying results. In Colorado and Utah, a small percentage of well pads leaked the vast majority of methane, whereas leakage was more equitably distributed among wells in Wyoming. The research team also

[1779] James Hansen et al., "Young People's Burden: Requirement of Negative CO2 Emissions," *Earth System Dynamics* 8 (2017): 577–616, https://doi.org/10.5194/esd-8-577-2017.
[1780] Emilio Godoy, "Mexico's Methane Emissions Threaten the Environment," *Inter Press Service News Agency*, July 8, 2017, sec. Energy, http://www.ipsnews.net/2017/07/mexicos-methane-emissions-threaten-environment/.

found variations that were dependent on oil/gas/water content as well as on the numbers of wells per well pad. In sum, emissions from well pads contributed significantly to basin-wide methane emissions but varied depending on location. [Note: the authors identify XTO Energy as a cost share partner in this study.][1781]

- April 18, 2017 – San Juan Basin in the four-corner region of Utah, Arizona, New Mexico, and Colorado, is one of the largest coal-bed methane producing regions in North America. Between 2003 and 2015, natural gas production declined, and yet, as revealed by atmospheric sampling from aircraft flying over the basin, methane emissions did not decrease during this same time period. These results confirm earlier findings from a satellite study that also showed no declines in regional methane concentrations in spite of significant declines in natural gas production. According to the authors, the likely explanation for the region's persistent, elevated methane levels is increased oil drilling in the basin.[1782]

- February 9, 2017 – Using ground-based monitoring methods, a team led by Drexel University researchers monitored a range of emissions, including methane, in two intensively drilled regions of the Marcellus Shale basin in Pennsylvania. The goal was to understand the concentrations and sources of relevant air pollutants that had previously been reported as impacts of drilling and fracking operations. Airborne methane concentrations were higher in southwestern Pennsylvania as compared to northeastern Pennsylvania. The authors conclude that urban-like levels of air pollutants in rural Pennsylvania are likely due to emissions from oil and gas operations in the Marcellus Shale basin.[1783]

- January 9, 2017 – A modeling study found that short-lived greenhouses gases, such as methane, contribute to thermal expansion of the ocean over much longer time scales than their brief atmospheric lifetimes might otherwise predict. "Actions taken to reduce emissions of short-lived gases could mitigate centuries of additional future sea-level rise."[1784]

- December 12, 2016 – As part of the interdisciplinary Global Carbon Project, a consortium of scientists undertook a meta-analysis that synthesizes many hundreds of individual studies in order to better understand the global methane cycle. Integrating atmospheric measurements with ground-based data, the researchers found more uncertainty in the emissions from natural sources than from human activities. For the

[1781] Anna M. Robertson et al., "Variation in Methane Emission Rates from Well Pads in Four Oil and Gas Basins with Contrasting Production Volumes and Compositions," *Environmental Science & Technology* 51, no. 15 (2017): 8832–40, https://doi.org/10.1021/acs.est.7b00571.
[1782] Mackenzie L. Smith et al., "Airborne Quantification of Methane Emissions over the Four Corners Region," *Environmental Science & Technology* 51, no. 0 (2017): 5832–37, https://doi.org/10.1021/acs.est.6b06107.
[1783] J. Douglas Goetz et al., "Analysis of Local-Scale Background Concentrations of Methane and Other Gas-Phase Species in the Marcellus Shale," *Elementa: Science of the Anthropocene* 5, no. 1 (2017), https://doi.org/10.1525/elementa.182.
[1784] Kirsten Zickfeld, Susan Solomon, and Daniel M. Gilford, "Centuries of Termal Sea-Level Rise Due to Anthropogenic Emissions of Short-Lived Greenhouse Gases," *Proceedings of the National Academy of Sciences U.S.A.* 114, no. 4 (2017): 657–62, https://doi.org/10.1073/pnas.1612066114.

2003–2012 decade, global methane emissions were 558 teragrams per year (range of 540–568), with 60 percent of global methane emissions attributed to anthropogenic sources of all kinds and with a significant contribution (likely at least 39 percent) from oil and gas production operations.[1785]

- December 12, 2016 – An editorial published in *Environmental Research Letters* by an international team of scientists urges immediate attention to quantify and reduce methane emissions. "Unlike CO2, atmospheric methane concentrations are rising faster than at any time in the past two decades and, since 2014, are now approaching the most greenhouse-gas-intensive scenarios." The authors present methods of evaluating anthropogenic and biogenic sources of methane, as from agricultural practices and project future methane emissions.[1786]

- November 8, 2016 – The government of Scotland released a report confirming that the pursuit of unconventional oil and gas extraction would make more difficult the nation's goal of meeting its climate targets on greenhouse gas emissions.[1787]

- November 1, 2016 – A life cycle analysis of greenhouse gas emissions from fracking operations in the Marcellus Shale region found that upstream activities associated with the use and transportation of chemicals, water, and sand mining contributed relatively lower emissions than downstream phases of the fracking process, which include gas combustion, methane leakage, venting, and flaring.[1788]

- October 5, 2016 – A new inventory of worldwide methane emissions from various sources finds that methane emissions from the fossil fuel industry are 20-60 percent higher than previously thought.[1789] This discovery, based on isotopic fingerprinting of methane sources, has prompted researchers to call for revisions to current climate prediction models and for a renewed emphasis on reducing methane emissions as a necessary tool for combating climate change.[1790]

- September 26, 2016 – In ratifying the Paris Climate Agreement, the United States pledged to reduce its greenhouse gas emissions 26-28 percent by 2025 as compared to 2005 levels. A research team from Lawrence Berkeley National Laboratory found that

[1785] Marielle Saunois et al., "The Global Methane Budget 2000-2012," *Earth System Science Data* 8 (2016): 697–751, https://doi.org/10.5194/essd-8-697-2016.
[1786] Marielle Saunois et al., "The Growing Role of Methane in Anthropogenic Climate Change," *Environmental Research Letters* 11, no. 12 (2016): 120207, https://doi.org/10.1088/1748-9326/11/12/120207.
[1787] Committee on Climate Change, "Unconventional Oil and Gas: Compatibility With Scottish Greenhouse Gas Emissions Targets," Research and Analysis (Energy and Climate Change Directorate, Scotland, November 8, 2016), http://www.gov.scot/Resource/0050/00509324.pdf.
[1788] Christopher Sibrizzi and Peter LaPuma, "An Assessment of Life Cycle Greenhouse Gas Emissions Associated With the Use of Water, Sand, and Chemicals in Shale Gas Production of the Pennsylvania Marcellus Shale," *Journal of Environmental Health* 79, no. 4 (2016): 8–15.
[1789] Stefan Schwietzke et al., "Upward Revision of Global Fossil Fuel Methane Emissions Based on Isotope Database," *Nature* 538 (2016): 88–91, https://doi.org/10.1038/nature19797.
[1790] Adam Vaughan, "Fossil Fuel Industry's Methane Emissions Far Higher Than Thought," *The Guardian*, October 5, 2016, https://www.theguardian.com/environment/2016/oct/05/fossil-fuel-industrys-methane-emissions-far-higher-than-thought.

the United States is on track to miss this target, in large part because of soaring methane emissions.[1791, 1792]

- September 12, 2016 – Using isotopic analysis and archived air samples collected from 1977 to 1998, as well as more contemporary data, a team of researchers from Oregon presented "strong evidence" that methane emissions from fossil fuel sectors were approximately constant in the 1980s and 1990s but then increased significantly between 2000 and 2009. Over the same time period, methane emissions from biomass burning, rice cultivation, and wetlands decreased. These results contradict the findings of earlier studies that used atmospheric ethane as a marker for methane and had concluded that fugitive fossil fuel emissions fell during much of that period. (More recent studies show that ethane emissions are increasing again.)[1793, 1794, 1795]

- July 11, 2016 – A group of 130 environmental and health organizations signed a formal complaint with the Inspector General of the U.S. Environmental Protection Agency (EPA) about a pivotal 2013 study that was published in the *Proceedings of the National Academies of Sciences* and which was led by University of Texas chemist David T. Allen. The letter accused Allen of "systemic fraud, waste, and abuse" for his reliance on an inaccurate measurement device that was known to underestimate methane levels. Partially funded by the oil industry, Allen's study reported very low methane emission rates as part of a large survey of 190 drilling and fracking sites across the nation. That flawed study was influential, said complainants, in preventing EPA from recognizing the magnitude of methane leakage from drilling and fracking operations.[1796] (See also the entry below for March 24, 2015.)

- June 17, 2016 – A comparative assessment of emerging methods for measuring methane emissions from different sources recommends combining analytic methods with chemical mass balance (CMB) methods. The CMB system is currently used in the Barnett Shale oil

[1791] Jeffery B. Greenblatt and Max Wei, "Assessment of the Climate Commitments and Additional Mitigation Policies of the United States," *Nature Climate Change* 6 (2016): 1090–93, https://doi.org/10.1038/nclimate3125.
[1792] Chris Mooney, "The U.S. Is on Course to Miss Its Emissions Goals, and One Reason Is Methane," *The Washington Post*, September 26, 2016, sec. Climate and Environment, https://www.washingtonpost.com/news/energy-environment/wp/2016/09/26/the-u-s-is-on-course-to-miss-its-emissions-goals-and-one-reason-is-methane/?utm_term=.80df24676a21.
[1793] A. L. Rice et al., "Atmospheric Methane Isotopic Record Favors Fossil Sources Flat in 1980s and 1990s With Recent Increase," *Proceedings of the National Academy of Sciences U.S.A.* 113, no. 39 (2016): 10791–96, https://doi.org/10.1073/pnas.1522923113.
[1794] C. Harvey, "Scientists May Have Solved a Key Mystery About the World's Methane Emissions," *The Washington Post*, September 13, 2016, sec. Climate and Environment, https://www.washingtonpost.com/news/energy-environment/wp/2016/09/13/the-answer-to-the-global-methane-mystery-fossil-fuels-a-study-finds/?utm_term=.64a94b9abf4e.
[1795] Camille von Kaenel, "Debate Rises over Real Source of Higher Methane Emissions," *Scientific American*, September 13, 2016, sec. Environment, https://www.scientificamerican.com/article/debate-rises-over-real-source-of-higher-methane-emissions/.
[1796] Jeff Johnson, "Pivotal Study on Methane Leaks From U.S. Oil and Natural Gas Wells Under Fire," *Chemical & Engineering News*, July 11, 2016, http://cen.acs.org/articles/94/i28/Pivotal-study-methane-leaks-US.html.

and gas production region in Texas as an approach to tracing methane emissions back to their sources.[1797]

- May 25, 2016 – As part of the first field study to directly measure methane emissions from the heavily drilled Bakken Shale formation in northwestern North Dakota, a team led by atmospheric chemist Jeff Peischl at NOAA flew research aircraft over the region in May 2014. The researchers derived a methane emission rate of 275,000 tons of methane per year, which is similar to the rate of methane leakage in the Front Range area of Colorado but significantly lower than previous studies of the Bakken area that relied on satellite remote sensing data during an earlier time period (2006-2011). Analyzing the chemical composition of air samples, the NOAA team determined that almost all of the methane originated with oil and gas operations, rather than with natural or agricultural sources, and estimated a leakage rate of 4.2-8.4 percent.[1798] Scaled to production, this emission rate is slightly lower than that estimated by EPA in its recently revised inventory.[1799, 1800] (See April 15, 2016 entry below.)

- April 15, 2016 – In its 21st annual greenhouse gas inventory, which includes 2014 data, the EPA increased its leakage assessment from oil and gas operations by 34 percent. For oil production alone, the EPA more than doubled its estimates of methane emissions. Further, in an admission that the agency had been historically underestimating methane leaks, the EPA also retroactively increased estimates of past emissions from the fossil fuel sector as expressed in prior inventories.[1801, 1802] In an accompanying news release, the agency said, "Data on oil and gas show that methane emissions from the sector are higher than previously estimated. The oil and gas sector is the largest emitting-sector for methane and accounts for a third of total U.S. methane emissions."[1803] Past EPA inventories had identified livestock as the number one source of U.S. methane. These annual inventories fulfill the EPA's obligations under the United Nations Framework Convention on Climate Change, signed and ratified by the United States in 1992, and attempt to identify and quantify U.S. anthropogenic sources and sinks of greenhouse

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[1797] David Allen, "Attributing Atmospheric Methane to Anthropogenic Emission Sources," *Accounts of Chemical Research* 49, no. 7 (2016): 1344–50, https://doi.org/10.1021/acs.accounts.6b00081.
[1798] Jeff Peischl et al., "Quantifying Atmospheric Methane Emissions From Oil and Natural Gas Production in the Bakken Shale Region of North Dakota," *Journal of Geophysical Research: Atmospheres* 121, no. 10 (2016): 6101–11, https://doi.org/10.1002/2015JD024631.
[1799] National Oceanic and Atmospheric Administration, "North Dakota's Bakken Oil and Gas Field Leaking 275,000 Tons of Methane per Year," Press Release (U.S. Department of Commerce, May 10, 2016), http://www.noaa.gov/news/north-dakota-s-bakken-oil-and-gas-field-leaking-275000-tons-of-methane-year.
[1800] James MacPherson, "A New Study Says the Oil-Producing Region of North Dakota and Montana Leaks 275,000 Tons of Methane Annually," *U.S. News*, May 11, 2016, http://www.usnews.com/news/science/articles/2016-05-11/study-bakken-oil-field-leaks-275-000-tons-of-methane-yearly.
[1801] U.S. Environmental Protection Agency, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014," April 15, 2016, https://www.epa.gov/sites/production/files/2016-04/documents/us-ghg-inventory-2016-main-text.pdf.
[1802] Jeff Johnson, "Oil, Natural Gas Operations Now Top U.S. Methane Emitters," *Chemical & Engineering News*, April 25, 2016, http://cen.acs.org/articles/94/i17/Oil-natural-gas-operations-top.html?type=paidArticleContent.
[1803] U.S. Environmental Protection Agency, "EPA Publishes 21st Annual U.S. Greenhouse Gas Inventory," Press Release, April 15, 2016, https://archive.epa.gov/epa/newsreleases/epa-publishes-21st-annual-us-greenhouse-gas-inventory.html.

gases for the time period 1990 and forward. The upward revision in both past and current inventories is a reflection of changing methodologies for measuring methane leaks.[1804] Older methods included the incorporation of "bottom-up" data supplied by the oil and gas industry, without attention to high-emitting or super-emitting sources or possible sources of error introduced by flawed measuring equipment. In addition, the use of a Global Warming Potential multiplier of 25 for methane, which is based on a 100-year time horizon, rather than 86 for a 20-year time horizon, has come under sustained criticism given the urgency of the climate crisis.[1805, 1806]

- April 7, 2016 – Since 2009, corresponding to the advent of the U.S. shale gas boom, North American ethane emissions have increased by 5 percent per year. This trend represents a reversal of a previous multi-decade decline (mid-1980s until the end of the 2000s) in the abundance of atmospheric ethane that had been attributed to the reduction of fugitive emissions from fossil fuel sources. These are the findings of an international research team, which analyzed remote sensing data gathered by the Network for the Detection of Atmospheric Composition Change at globally distributed ground-based sites. Ethane is a volatile organic compound (VOC) that readily reacts with nitrogen oxides in the presence of sunlight to create ground-level ozone (smog). Also a potent greenhouse gas, ethane is co-released along with methane from drilling and fracking sites. The source of two-thirds of the ethane in Earth's atmosphere is leakage from natural gas wells and pipelines. Because ethane is co-emitted with methane and can serve as a marker for it, this documentation of a sharp, recent uptick in atmospheric ethane is part of a larger body of evidence suggesting that U.S. drilling and fracking operations are driving up global methane levels.[1807] (See also entry dated June 13, 2016 in Air Pollution section].)

- April 5, 2016 – Helicopter-based infrared camera surveys of more than 8,000 oil and gas wells in seven U.S. regions found that well pads emit considerably more methane and VOCs than captured by earlier inventories. Moreover, these emissions were widely and unpredictably variable from site to site and from well to well. Between 1 and 14 percent of oil and gas well pads surveyed were high emitters of hydrocarbons and VOCs, with the greatest number observed in oil-producing areas and in areas with horizontal drilling. Further, while some leakage was intentional or part of routine maintenance operations, unplanned releases from malfunctioning equipment were also common, as were combustion emissions from flares and compressor engine exhaust. Over 90 percent of total airborne emissions from well pads originated with vents and hatches on

[1804] Chris Mooney, "The U.S. Has Been Emitting a Lot More Methane Than We Thought, Says EPA.," *The Washington Post*, April 15, 2016, sec. Climate and Environment, https://www.washingtonpost.com/news/energy-environment/wp/2016/04/15/epa-issues-large-upward-revision-to-u-s-methane-emissions/?utm_term=.eca9c599ff09.
[1805] Thomas Sumner, "EPA Underestimates Methane Emissions," *Science News*, April 14, 2016, sec. Environment, https://www.sciencenews.org/article/epa-underestimates-methane-emissions.
[1806] Tim Profeta, "Study, EPA Spotlight Methane Emissions From Oil and Gas Industry," *National Geographic*, March 3, 2016.
[1807] Bruno Franco et al., "Evaluating Ethane and Methane Emissions Associated With the Development of Oil and Natural Gas Extraction in North America," *Environmental Research Letters* 11 (2016): 044010, https://doi.org/10.1088/1748-9326/11/4/044010.

aboveground storage tanks. These findings deeply undercut the assumption in the EPA's Oil & Gas Emission Estimation Tool that tank control systems offer 100 percent capture efficiency. The overall inability to predict which sites were super-emitters (meaning that they leaked into the air more than 200 cubic feet of methane and VOCs per hour) demonstrates that continuous, site-specific monitoring would be required to identify and remediate methane leaks from drilling and fracking operations.[1808] In a comment about the findings to *Inside Climate News*, Cornell University engineer Anthony Ingraffea, who was not an author of the paper, said, "It makes regulation very difficult. If you have all these possible sites where you can have leaks, you can never have enough inspectors with all the right equipment being in all the right places at all the right times. It's too complex a system."[1809]

- March 10, 2016 – Attempting to explain a methane plateau between 1999 and 2006 within otherwise almost continuously increasing levels of atmospheric methane since the dawn of the industrial revolution, an international team of atmospheric scientists reconstructed the global history of methane and used isotopic carbon fingerprinting to parse the sources of its emission. Thermogenic emissions were assumed to result from fossil-fuel sources, while biogenic sources were assumed to arise from wetlands and agricultural operations. Based on a geographic distribution of methane revealed by remote sensing, the authors concluded that agricultural emissions, especially increases in livestock inventories and rice cultivation, were the most likely drivers of observed global methane increases from 2006 to 2014.[1810] These results stand in contrast to other contemporaneous and recent studies that have supplied evidence for the role of oil and gas extraction in the recent upsurge in atmospheric methane.[1811] (See entry for February 16, 2016 below.)

- February 16, 2016 – A Harvard-led team used both satellite retrievals and surface observations to estimate that methane emissions in the United States increased by more than 30 percent over the past twelve years. These findings, which contradict the 10 percent decline reported by the EPA, suggest that the United States could be responsible for 30-60 percent of the recent global spike in atmospheric methane.[1812, 1813] Since 2015, research on atmospheric methane has frequently relied on an "inverse method" to

[1808] David R. Lyon et al., "Aerial Surveys of Elevated Hydrocarbon Emissions from Oil and Gas Production Sites," *Environmental Science & Technology* 50 (2016): 4877–86, https://doi.org/10.1021/acs.est.6b00705.
[1809] Phil McKenna, "Researchers Find No Shortcuts for Spotting Wells That Leak the Most Methane," Inside Climate News, April 8, 2016, https://insideclimatenews.org/news/08042016/big-methane-leaks-superemitters-oil-gas-production-climate-change-edf/.
[1810] Hinrich Schaefer et al., "A 21st-Century Shift From Fossil-Fuel to Biogenic Methane Emissions Indicated by 13CH4," *Science* 352, no. 6281 (2016): 80–84, https://doi.org/10.1126/science.aad2705.
[1811] Phil McKenna, "The Mystery of the Global Methane Rise: Asian Agriculture or U.S. Fracking?," *Inside Climate News*, March 10, 2016, sec. Fossil Fuels, https://insideclimatenews.org/news/10032016/mysterious-global-methane-rise-asian-agriculture-or-us-fracking.
[1812] A. J. Turner et al., "A Large Increase in U.S. Methane Emissions Over the Past Decade Inferred From Satellite Data and Surface Observations," *Geophysical Research Letters* 43, no. 5 (2016): 2218–24, https://doi.org/10.1002/2016GL067987.
[1813] Bobby Magill, "Study Ties U.S. to Spike in Global Methane Emissions," *Climate Central*, February 16, 2016, http://www.climatecentral.org/news/us-60-percent-of-global-methane-growth-20037.

optimize emission estimates by combining "bottom-up" and "top-down" data, yet data from different sources have not yielded consistent estimates of methane emissions and levels. Three major sources (Wecht et al. [2014], Miller et al. [2013], and Turner et al. [2015]) all found maximum emissions in the South Central United States, with spatial overlaps that made separating livestock sources from oil and gas sources difficult. Taking into account the time period investigated by differing studies reveals an increasing trend in methane emissions, with an increase of 38 percent from 2004 to 2011, a period of greatly increasing drilling activity. This trend is confirmed by analyzing temporal trends in satellite data. While this account still differs from the EPA's inventory in 2014 showing a 3 percent decrease in oil and gas emissions over that same time period, the EPA's data presumed better control of measured leaks, which may not correlate with better control of overall emissions.

- January 29, 2016 – Working in the Marcellus Shale Basin, a Carnegie Mellon research team compared methane emissions from older conventional gas wells (those that were vertically drilled) and newer, unconventional gas wells (those that combined fracking with horizontal drilling). Measured by facility, the mean emission rate for unconventional wells was 23 times higher than that of conventional wells. This difference, in part, was attributed to the larger size of unconventional well pads, which, typically, have multiple wells per pad, more ancillary equipment, and produce more gas. When corrected for production, the conventional wells leaked more—that is to say, they lost a comparably larger fraction of methane per unit of production—likely due to "unresolved equipment maintenance issues." Altogether, the authors concluded, these new emissions data show that the recently instituted Pennsylvania Department of Environmental Protection's (PA DEP) methane emissions inventory substantially underestimates facility-level methane emissions. Five unconventional well sites included in this study leaked 10-37 times more methane than estimated in the state inventory.[1814]

- January 25, 2016 – Cornell University scientists introduced an innovative methodology for assessing potential climate impacts of alternative choices and used it to demonstrate that emissions of the two most important greenhouse gases (carbon dioxide and methane), calculated as time-integrated radiative forcing, are lower with heat pump water heaters than any other means of heating water. Further, their calculations showed that heat pump water heaters powered by coal-generated electricity achieve greater net climatic benefit than heaters powered by natural gas, while even greater benefits may be achieved by combining heat pump water heaters with electricity generated by renewable sources. The authors proposed and justified a methane emission rate of 3.8 percent for conventional shale gas, which is therefore offered as a lower bound for future, tightly controlled methane emissions from unconventional gas activities. The authors also made their web-based tool for evaluating the greenhouse gas footprint of reference and

[1814] Mark Omara et al., "Methane Emissions from Conventional and Unconventional Natural Gas Production Sites in the Marcellus Shale Basin," *Environmental Science & Technology* 50, no. 4 (2016): 2099–2107, https://doi.org/10.1021/acs.est.5b05503.

alternative technologies and its source code available to the public (at http://www.eeb.cornell.edu/howarth/methane/tool.htm).[1815]

- December 22, 2015 – To reconcile troubling divergences in published estimates of methane emissions, in which "top-down" estimates, based on atmospheric or satellite sampling, often exceed "bottom-up" estimates, based on ground-level sampling or individual source reports, researchers used a combination of repeated mass balance measurements plus ethane fingerprinting to improve top-down estimates and incorporated a more complete and detailed count of facilities to improve bottom-up estimates.[1816] The results, as demonstrated in the Barnett Shale oil and gas-producing region of Texas, revealed a convergence of estimates to within 10 percent for fossil methane and 0.1 percent for total methane, with predicted methane emissions 90 percent larger than those estimated by the EPA's Greenhouse Gas Inventory. Exclusion of additional problematic studies might have resulted in even greater convergence and higher estimates.[1817] The agreement between top-down and bottom-up estimates demonstrates that well-designed surveys using either approach can be useful, with spatially resolved bottom-up estimates pointing toward production sites as the source of 53 percent of emissions, compressor stations 31 percent of emissions, and processing plants 13 percent of emissions. The Barnett shale emission rate of 1.5 percent calculated in this study is low enough (less than 3 percent) to suggest that gas fired electricity production in this region causes less climate forcing than coal-fired electricity, but it is high enough (greater than 1 percent) to argue against the conversion of diesel-powered freight trucks to compressed natural gas. Gas production practices and heavier activity in other basins may lead to higher emission rates, as may the storage and long-distance or very long-distance transmission of natural gas.

- December 22, 2015 – Climate scientists want the United Nations to stop expressing the heat-trapping potential of methane over a 100-year time frame and instead use a twenty-year time frame when generating global warming potential, the conversion factor that allows policymakers to compare methane's ability to trap heat with that of carbon dioxide. Methane is a far more potent heat-trapping gas than is carbon dioxide, but it is also shorter lived. By convention, policymakers have used a 100-year time frame when calculating global warming potentials. However, there is no scientific reason to do so, and many scientific critics argue that choosing this time scale veils the true climate impacts of natural gas and "makes the gas appear more benign than it is."[1818]

[1815] Bongghi Hong and Robert W. Howarth, "Greenhouse Gas Emissions From Domestic Hot Water: Heat Pumps Compared to Most Commonly Used Systems," *Energy Science & Engineering* 42, no. 2 (2016): 123–33, https://doi.org/10.1002/ese3.112.
[1816] Daniel Zavala-Araiza et al., "Reconciling Divergent Estimates of Oil and Gas Methane Emissions," *Proceedings of the National Academy of Sciences U.S.A.* 112, no. 51 (2015), https://doi.org/10.1073/pnas.1522126112.
[1817] Lisa Song, "Texas Fracking Zone Emits 90% More Methane Than EPA Estimated," *Inside Climate News*, December 7, 2015, https://insideclimatenews.org/news/07122015/methane-emissions-texas-fracking-zone-90-higher-epa-estimate.
[1818] Gayathri Vaidyanathan, "How Bad of a Greenhouse Gas Is Methane?," *Scientific American*, December 22, 2015, https://www.scientificamerican.com/article/how-bad-of-a-greenhouse-gas-is-methane/.

- November 25, 2015 – Using reports from countries and companies with proved reserves of recoverable oil, natural gas, and coal, an analysis published in *Global Environmental Change* shows that full production of these resources would use up 160 percent of the world's estimated remaining carbon budget (designed to restrict anthropogenic climate change to equal to or less than 2° C). While 76 percent of reserves are owned by states or state entities, the relatively smaller amount of reserves owned by investors poses the greater immediate threat, since those companies are more likely poised to produce, refine, and deliver fossil fuels to global markets in the near term. However, exploitation of existing proved reserves controlled by the private sector alone does not lead to warming above the 2° limit, if it is not accompanied by exploration for and development of new reserves. Future considerations of fossil fuel use should focus not only on reducing private sector contributions but also on reducing contributions from countries that have historically dominated or currently dominate emissions, and especially nation-states with large undeveloped reserves.[1819]

- November 9, 2015 – Including data available through 2014, the World Meteorological Organization (WMO) reported that globally averaged levels of carbon dioxide, methane, and nitrous oxide reached new highs in 2014, with values, respectively, "143%, 254% and 121% of pre-industrial (1750) levels."[1820, 1821] While the atmospheric increase in carbon dioxide has slowed, methane and nitrous oxide levels continue to increase. Measurements from the WMO's Global Watch Programme point to wetlands in the tropics and anthropogenic sources at mid-latitudes of the northern hemisphere as the sources of increased methane over the past decade.

- October 8, 2015 – As a foundation for policy recommendations, Cornell University biogeochemist Robert Howarth summarized and analyzed the evidence documenting the magnitude of methane emissions related to oil and gas development in the United States since 2007. With estimated emission rates ranging from 3.8-12 percent, the high radiative forcing of methane over a twenty-year period prevents natural gas from serving as a bridge fuel. Instead of further investments in natural gas, Howarth proposes a rapid transition to electric powered vehicles for transportation, high-efficiency heat pumps for space and water heating, and imposition of a methane tax that is roughly 86 times higher than currently proposed carbon taxes, which typical address only carbon dioxide.[1822]

[1819] Richard Heede and Naomi Oreskes, "Potential Emissions of CO2 and Methane From Proved Reserves of Fossil Fuels: An Alternative Analysis," *Global Environmental Change* 36 (2016): 12–20, https://doi.org/10.1016/j.gloenvcha.2015.10.005.
[1820] World Meteorological Organization, "The State of Greenhouse Gases in the Atmosphere Based on Global Observations Through 2014," WMO Greenhouse Gas Bulletin 11, November 9, 2015, https://library.wmo.int/doc_num.php?explnum_id=7243.
[1821] Tom Miles, "CO2 Levels Hit Record High for 30th Year in a Row," *Scientific American*, November 9, 2015, https://www.scientificamerican.com/article/co2-levels-hit-record-high-for-30th-year-in-a-row/.
[1822] Robert W. Howarth, "Methane Emissions and Climatic Warming Risk From Hydraulic Fracturing and Shale Gas Development: Implications for Policy," *Energy and Emission Control Technologies* 3 (2015): 45–54, https://doi.org/10.2147/EECT.S61539.

Howarth also noted that the EPA "has seriously underestimated the importance of methane emissions in general—and from shale gas in particular."[1823]

- August 4, 2015 – A developer of high flow sampling technology determined that a commonly used instrument to quantify methane leakage has unreliable sensors and malfunctions in ways that vastly underreport emissions by factors of three to five. More than 40 percent of the compiled national methane inventory may be affected by this measurement failure, according to the author of this study.[1824] The implications of this discovery for our understanding of system-wide methane leakage rates from drilling and fracking operations are not known, but they do call into question the results of at least one major study of methane emissions that relied on this device for collecting data. This is the second of two studies that finds that the primary tool approved by the EPA for measuring and reporting emissions of methane fails to function properly when used as directed by the manufacturer. (See also entry below dated March 24, 2015.)

- July 21, 2015 – An international team of researchers investigated the claim that the fracking boom, which has dramatically increased supplies of natural gas in the United States, is the main driver of the modest decline in carbon dioxide emissions since 2007. Conventional wisdom, as expressed by the Third National Climate Assessment of the U.S. Global Change Research Program, attributes the drop in emissions to a shift away from carbon dioxide-intensive coal and toward natural gas in power plants. But this team analyzed the sources of change in carbon dioxide emissions and, using a tool called input-output structural decomposition analysis, documented that the economic downturn, not fuel switching in the power sector, was the explanation for declining carbon dioxide emissions since 2007. The single biggest impact on U.S. emissions was changes in the volume of goods and services consumed. Between 2007 and 2013, driven by a huge drop in the volume of capital investment, emissions associated with capital formation decreased by almost 25 percent. During the same period, emissions related to household consumption decreased by 11 percent.[1825]

- July 7, 2015 – A scientific opinion piece by Environmental Defense Fund researchers involved in a group of 11 studies on methane emissions in Texas' Barnett Shale provided an overview and orientation to new research that either measured or estimated methane emissions from oil and gas operations. Research from both top-down estimates (based on measuring atmospheric methane or related compounds at regional or larger scales) and bottom-up measurements (made directly from components or at ground level near studied sites) demonstrated that methane emissions from oil and gas operations in the Barnett Shale region exceeded the emissions expected from the EPA's greenhouse gas inventory, which relies on industry self-reporting and excludes many compressor

[1823] "Two Studies Highlight Risks of Fracking-Released Methane," Weather.com, October 20, 2015, https://web.archive.org/web/20151021134023/https://weather.com/science/environment/news/studies-highlight-risks-of-methane-from-fracking.
[1824] Touché Howard, "University of Texas Study Underestimates National Methane Emissions at Natural Gas Production Sites Due to Instrument Sensor Failure," *Energy Science & Engineering* 3, no. 5 (2015): 443–55, https://doi.org/10.1002/ese3.81.
[1825] Kuishuang Feng et al., "Drivers of the US CO2 Emissions 1997–2013," *Nature Communications* 6 (2015): 7714, https://doi.org/10.1038/ncomms8714.

stations. The new research detailed the importance of addressing high-emitting landfills and natural gas facilities ("super-emitters") and malfunctioning equipment in efforts to control ongoing methane emissions.[1826]

- May 28, 2015 – A comprehensive working paper from the New Climate Economy initiative of the Global Commission on the Economy and Climate at Stockholm Environment Institute found that the experience in the United States of substituting natural gas for oil was unlikely to be replicated around the globe and probably will not provide climate benefits unless coupled with strict controls on methane leakage, limits on total energy use, and policies to prevent the displacement of non-fossil fuel energy by methane. Citing multiple studies of the net climate impact of "more abundant, cheaper natural gas supplies," the Commission concluded that "both globally and for the United States, the increase in emissions from the scale effect [from increased energy consumption boosted by cheap natural gas and loss of potentially more expensive lower carbon approaches] fully offsets the emission benefits from the substitution effect, net of methane leakage."[1827, 1828]

- March 24, 2015 – A University of Cincinnati researcher and independent engineers documented that the Bacharach Hi-Flow Sampler (BHFS)—one of the only tools approved by the EPA for measuring and reporting emissions of methane from natural gas transmission, storage, and processing facilities—failed to function properly when used as indicated by the manufacturer. The BHFS, unless recalibrated daily and running revised software (or taking measurements in a nearly pure methane environment, which is exceedingly rare in the field), misreported high levels of natural gas by as much as an order of magnitude lower than actual concentration. A reanalysis of 2011 results from the City of Fort Worth Air Quality Study revealed at least seven instances for which the BHFS indicated sample concentrations at or below 5 percent when more reliable canister methane readings indicated concentrations that ranged from 6.1 percent to 90.4 percent. Inaccurate measurements like these can contribute to the discrepancy between "top-down" and "bottom-up" measurements of methane, with ground-level measurements from the BHFS potentially producing reports of falsely low emissions.[1829] This study was followed by another that further documented malfunctions in the BHFS device and called into question the results of a landmark 2013 survey of methane emissions at 190 drilling and fracking sites across the United States. That 2013 survey, from the University of

[1826] Robert Harriss et al., "Using Multi-Scale Measurements to Improve Methane Emission Estimates from Oil and Gas Operations in the Barnett Shale Region, Texas," *Environmental Science & Technology* 49, no. 13 (2015): 7525–26, https://doi.org/10.1021/acs.est.5b02305.
[1827] Michael Lazarus et al., "Natural Gas: Guardrails for a Potential Climate Bridge," New Climate Economy Contributing Paper (Stockholm Environment Institute, May 2015), https://mediamanager.sei.org/documents/Publications/Climate/NCE-SEI-2015-Natural-gas-guardrails-climate-bridge.pdf.
[1828] Simon Evans, "The Climate Benefits of a Gas Bridge Are Unlikely to Be Significant," *The Australian Business Review*, June 2, 2015, http://www.businessspectator.com.au/article/2015/6/2/policy-politics/climate-benefits-gas-bridge-are-unlikely-be-significant.
[1829] Touché Howard, Thomas W. Ferrara, and Amy Townsend-Small, "Sensor Transition Failure in the High Flow Sampler: Implications for Methane Emission Inventories of Natural Gas Infrastructure," *Journal of the Air & Waste Management Association* 65, no. 7 (2015): 856–62, https://doi.org/10.1080/10962247.2015.1025925.

Texas, relied on the BHFS device for collecting data and found very low leakage rates.[1830] (See also entry above dated August 4, 2015.)

- March 20, 2015 – A team led by Bruno Franco from the University of Liege in Belgium discovered an abrupt uptick in ethane levels at a mountaintop station in the Swiss Alps that is far removed from local pollution sources.[1831] In a later comment about this discovery, Franco said, "Since 2009, we observed increases of 5% per year here—it was completely unexpected."[1832] The team attributed the trend reversal to the natural gas boom in North America. Ethane is released together with methane from drilling and fracking operations and serves as a proxy for it. (See also the entry above for April 7, 2016.)

- March 9, 2015 – With specialized equipment in a mobile van, University of Colorado, NOAA, Environmental Defense Fund, and independent researchers continuously measured methane and ethane from public roads at sites downwind of potential emission sources, such as natural gas production wellheads, processing plants, and compressor stations. The sampling method and modeling allowed capture of multiple "accidental" plumes, acquired during long drives across the study region between planned measurements near large facilities. Sampling was not random but documented a large number of facilities with low methane emission rates (equal to or less than 10 kg/hr), with a smaller yet important number of facilities showing much higher emissions. Although the largest measured emission in this study (1,360 kg/hr) corresponded to approximately $1.2 million in lost revenue per year, the authors noted that, in this industry, the "leak fraction" or "proportional loss" levels they documented would generally translate into only a small proportion of lost revenue, probably not sufficient to prompt strong energy-sector self-regulation.[1833]

- March 1, 2015 – Using a simulation model, the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, writing for Germany's Federal Environmental Agency, found that shale gas was not a cheap option to reduce global greenhouse gas emissions. Multiple comparison simulations found that shale gas availability, especially in the short-term, tends to lead to higher emissions due to lower energy prices inducing higher use. The net result is higher costs to achieve compliance with climate targets. In this model, shale gas was also found to compete in an unhelpful

[1830] David T. Allen et al., "Measurements of Methane Emissions at Natural Gas Production Sites in the United States," *Proceedings of the National Academy of Sciences* 110 (2013): 17768–73, https://doi.org/10.1073/pnas.1304880110.
[1831] Bruno Franco et al., "Retrieval of Ethane From Ground-Based FTIR Solar Spectra Using Improved Spectroscopy: Recent Burden Increase Above Jungfraujoch," *Journal of Qualitative Spectroscopy and Radiative Transfer* 160 (2015): 36–49, https://doi.org/10.1016/j.jqsrt.2015.03.017.
[1832] Environmental Research Web, "Ethane Emissions Back on the Rise," May 23, 2016, http://environmentalresearchweb.org/cws/article/news/65093.
[1833] Tara I. Yacovitch et al., "Mobile Laboratory Observations of Methane Emissions in the Barnett Shale Region," *Environmental Science & Technology* 49, no. 13 (2015): 7889–95, https://doi.org/10.1021/es506352j.

way with renewable energy sources, resulting in reduced use of renewable energy sources and reduced investment in energy efficiency measures.[1834]

- January 8, 2015 – Using a single integrated modeling program that incorporates detailed estimates of the world's reserves of oil, gas, and coal and is consistent with a wide variety of prior modeling approaches, University College London researchers demonstrated that, around the world, "a third of oil reserves, half of gas reserves and over 80 per cent of current coal reserves should remain unused from 2010 to 2050" in order to meet a target of less than or equal to a 2 degree Celsius rise in global temperature. In addition, "development of resources in the Arctic and any increase in unconventional oil production are incommensurate with efforts to limit average global warming" below the 2 degree threshold. Calling for a "stark transformation" of our understanding of fossil fuel availability, the authors noted that, in a climate-constrained world, fears of scarcity of fossil fuels must be superseded by a commitment to preventing overuse of existing resources and reserves.[1835]

- November 26, 2014 – Stanford University and independent researchers compared coal and natural gas for power generation and concluded that the question of "whether natural gas plants are better than coal plants cannot be answered in the general case." During the period of plant operation, "natural gas plants can produce greater near-term warming than coal plants, with the same power output." They found that over time, natural gas plants can produce some reduction in near-term warming, but only if life cycle methane leakage rates are low and power plant efficiency is high. Relative to coal, there is the potential that "deployment of natural gas power plants could both produce excess near-term warming (if methane leakage rates are high) and produce excess long-term warming (if the deployment of natural gas plants today delays the transition to near-zero emission technologies)."[1836]

- October 23, 2014 – Adding to the debate about natural gas and climate change, a multi-center, international research team used a sophisticated, integrated approach to the global energy-economy-climate systems question and found no climate benefit to natural gas over other fossil fuels. As summarized by the editor of *Nature*,

> The development of hydraulic fracturing technologies has led to rapid growth in the use of natural gas as an energy source. Some evidence has suggested that this growing adoption of natural gas might lead a reduced greenhouse gas burden and consequent mitigation of climate change. This collaboration between five energy–climate modelling teams show that instead—under a scenario of abundant natural

[1834] Jan Kersting et al., "The Impact of Shale Gas on the Costs of Climate Policy" (Environmental Research of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, 2015), https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/climate_change_03_2015_the_impact_of_shale_gas_1.pdf.
[1835] Christophe McGlade and Paul Ekins, "The Geographical Distribution of Fossil Fuels Unused When Limiting Global Warming to 2° C," *Nature* 517 (2015): 187–90, https://doi.org/10.1038/nature14016.
[1836] Xiaochun Zhang, Nathan P. Myhrvold, and Ken Caldeira, "Key Factors for Assessing Climate Benefits of Natural Gas Versus Coal Electricity Generation," *Environmental Research Letters* 9, no. 11 (2014): 114022, https://doi.org/10.1088/1748-9326/9/11/114022.

gas availability—increased consumption will have little or no impact on climate change." The authors concluded, "although market penetration of globally abundant gas may substantially change the future energy system, it is not necessarily an effective substitute for climate change mitigation policy.[1837]

- October 6, 2014 – Utilizing satellite data for the Bakken and Eagle Ford formations, scientists from Germany, the United Kingdom, and the University of Maryland confirmed that higher "top-down" estimates of fugitive methane leaks from oil and gas fields (which are obtained via tall tower flask samples, aircraft measurements, and road surveys) are more accurate than lower "bottom-up" estimates (which are obtained by summing emissions from different types of known sources at sites provided by participating utility companies). According to "bottom-up" estimates, the average U.S. leakage rate ranges from 1.2-2.0 percent. But satellite data show much higher leakage rates: 10.1 percent (± 7.3 percent) and 9.1 percent (± 6.2 percent), for the Bakken and Eagle Ford formations, respectively. These higher estimates indicate that current inventories likely underestimate fugitive emissions and call into question any immediate climate benefit from switching from coal to natural gas. Similar results were seen for the Marcellus shale region, but as a result of technical and geographical limitations, the authors declined to quantify their results, pending future studies with enhanced equipment.[1838]

- September 24, 2014 – According to a paper published by scientists from the University of California and Stanford University, "… without strong limits on [greenhouse gas] emissions or policies that explicitly encourage renewable electricity, abundant natural gas may actually slow the process of decarbonization, primarily by delaying deployment of renewable energy technologies." The study builds on previous research by examining natural gas in a range of supply curves, with a tested economic model, and across three different types and levels of climate policy. Researchers found that abundant natural gas, even with low rates of methane leakage, does little to reduce—and may increase—greenhouse gases. They conclude that delaying deployment of renewable energy technologies "may actually exacerbate the climate change problem in the long term."[1839]

- September 2, 2014 – Analyzing the level of greenhouse gas emissions attributable to electricity from natural-gas-fired power plants and coal-fired power plants, economist Chris Busch and physicist Eric Gimon conclude that, over short time frames and at high rates of leakage, natural gas offers little benefit compared to coal and could exacerbate global warming. Although Busch and Gimon acknowledge that natural gas offers some reductions in greenhouse gas emissions over longer time frames, they point out that such reductions are not large enough for natural gas to play an expanded role in efforts to

[1837] Haewon McJeon et al., "Limited Impact on Decadal-Scale Climate Change From Increased Use of Natural Gas," *Nature* 514 (2014): 482–482, https://doi.org/10.1038/nature13837.
[1838] Oliver Schneising et al., "Remote Sensing of Fugitive Methane Emissions From Oil and Gas Production in North American Tight Geologic Formations," *Earth's Future* 2, no. 10 (2014): 548–58, https://doi.org/10.1002/2014EF000265.
[1839] Christine Shearer et al., "The Effect of Natural Gas Supply on US Renewable Energy and CO2 Emissions," *Environmental Research Letters* 9, no. 9 (2014): 094008, https://doi.org/10.1088/1748-9326/9/9/094008.

manage emissions. They conclude that under the best of circumstances, natural gas-fired electric power offers a modest benefit toward abating climate change, while if poorly developed (i.e., with extensive methane leaks, estimated by these authors to be on the order of 4 percent or higher), or if used to displace energy efficiency or renewable energy, natural gas could seriously contribute to increased greenhouse gas emissions.[1840]

- August 5, 2014 – Reporting in *Scientific American,* the science news organization Climate Central outlined the natural gas-related factors that threaten any ability to achieve climate goals through the proposed Clean Power Plan. "No one has any idea how much methane is leaking from our sprawling and growing natural gas system. This is a major problem, because without a precise understanding of the leak rate natural gas could actually make climate change worse." Referring to an interactive Climate Central tool that runs various methane leakage scenarios, the article notes that, even given modest leak rates and an aggressive transition, "we could still end up with little or no climate benefits by 2030 after an enormous financial and political investment in natural gas."[1841]

- July 25, 2014 –EPA's Office of Inspector General reports that the agency "has placed little focus and attention on reducing methane emissions from pipelines in the natural gas distribution sector." According to this report, the EPA acknowledged in 2012 that leaks from natural gas pipelines "accounted for more than 13 million metric tons of carbon dioxide equivalent emissions," are almost 100 percent methane, and represent more than 10 percent of total methane emissions from natural gas systems in the United States. Nevertheless, as report went on to note, the EPA does not have the partnerships in place to begin controlling methane leaks, such as with the Pipeline and Hazardous Materials Safety Administration, nor has it conducted a comprehensive analysis of emissions factors, relying instead on a 1996 study with a "high level of uncertainty."[1842]

- May 15, 2014 – A recent review of existing data on life cycle emissions of methane from natural gas systems concluded that, as a strategy for addressing climate change, natural gas is a "bridge to nowhere." The review found that, over a 20-year time frame, natural gas is as bad as or worse than coal and oil as a driver of climate change.[1843] Referencing this review and other recent studies, *Bloomberg Business News* reported that the EPA has underestimated the impact of methane leakage resulting from the production, transmission, and distribution of natural gas and is using outdated estimates of methane's potency compared to more recent estimates from the Intergovernmental Panel on Climate Change (IPCC).[1844]

[1840] Chris Busch and Eric Gimon, "Natural Gas versus Coal: Is Natural Gas Better for the Climate?," *The Electricity Journal* 27, no. 7 (2014): 97–111, https://doi.org/10.1016/j.tej.2014.07.007.
[1841] Climate Central, "Methane Leak Rate Proves Key to Climate Change Goals," *Scientific American*, August 5, 2014, http://www.scientificamerican.com/article/methane-leak-rate-proves-key-to-climate-change-goals/.
[1842] U.S. Environmental Protection Agency Office of Inspector General, "Improvements Needed in EPA Efforts to Address Methane Emissions From Natural Gas Distribution Pipelines," July 25, 2014, https://www.epa.gov/sites/default/files/2015-09/documents/20140725-14-p-0324_0.pdf.
[1843] Robert W. Howarth, "A Bridge to Nowhere: Methane Emissions and the Greenhouse Gas Footpring of Natural Gas," *Energy Science & Engineering* 2, no. 2 (2014): 47–60, https://doi.org/10.1002/ese3.35.
[1844] A. Childers, "EPA Understimates Fracking's Impact on Climate Change.," *Bloomberg*, May 9, 2014, http://www.bloomberg.com/news/2014-05-09/epa-underestimates-fracking-s-impact-on-climate-change.html.

- April 25, 2014 – A reassessment of the heat-trapping potential of greenhouse gases revealed that current methods of accounting underestimate the climate-damaging impact of methane pollution from all sources, including drilling and fracking operations.[1845]

- April 14, 2014 – A study from researchers at Purdue University, NOAA, Cornell University, University of Colorado at Boulder, and Pennsylvania State University, published in *Proceedings of the National Academy of Sciences* found very high levels of methane emissions above many wells being drilled at fracking sites in Pennsylvania. Levels were 100-1,000 times above the estimates of federal regulators, who have always assumed very low methane emissions as wells are drilled.[1846, 1847]

- February 26, 2014 – The United Nations' top environmental official, Achim Steiner, argued that the shale gas rush is "a liability" in efforts to slow climate change and that a switch from coal to natural gas is delaying critical energy transition to renewables.[1848]

- February 13, 2014 – A major study in *Science* by Stanford University, Massachusetts Institute of Technology, and the U.S. Department of Energy found that methane leaks negate any climate benefits of natural gas as a fuel for vehicles, and that the EPA is significantly underestimating methane in the atmosphere.[1849] Lead author Adam R. Brandt told the *New York Times*, "Switching from diesel to natural gas, that's not a good policy from a climate perspective."[1850] This study also concluded that the national methane leakage rate is likely between 3.6 and 7.2 percent of production.

- January 15, 2014 – As reported by the *Guardian*, a new study by BP concluded that shale gas "…will not cause a decline in greenhouse gases" and will do little to cut carbon emissions.[1851]

[1845] Morgan R. Edwards and Jessika E. Trancik, "Climate Impacts of Energy Technologies Depend on Emissions Timing," *Nature Climate Change* 4 (2014): 347–52, https://doi.org/10.1038/NCLIMATE2204.
[1846] Dana R. Caulton et al., "Toward a Better Understanding and Quantification of Methane Emissions From Shale Gas Development," *Proceedings of the National Academy of Sciences*, 2014, https://doi.org/10.1073/pnas.1316546111.
[1847] Neela Banerjee, "EPA Drastically Underestimates Methane Released at Drilling Sites," *Los Angeles Times*, April 14, 2014, sec. Science, http://www.latimes.com/science/sciencenow/la-sci-sn-methane-emissions-natural-gas-fracking-20140414,0,2417418.story.
[1848] Suzanne Goldenberg, "Achim Steiner: Shale Gas Rush 'a Liability' in Efforts Slow Climate Change," *The Guardian*, February 26, 2014, http://www.theguardian.com/environment/2014/feb/26/achim-steiner-shale-gas-rush-climate-change-energy.
[1849] Adam R. Brandt et al., "Methane Leaks from North American Natural Gas Systems," *Science* 343, no. 6172 (2014): 733–35, https://doi.org/10.1126/science.1247045.
[1850] Coral Davenport, "Study Finds Methane Leaks Negate Benefits of Natural Gas as a Fuel for Vehicles," *The New York Times*, February 13, 2014, http://www.nytimes.com/2014/02/14/us/study-finds-methane-leaks-negate-climate-benefits-of-natural-gas.html?smid=tw-share.
[1851] Fiona Harvey and Terry Macalister, "BP Study Predicts Greenhouse Emissions Will Rise by Almost a Third in 20 Years," *The Guardian*, January 1, 2014, http://www.theguardian.com/business/2014/jan/15/bp-predicts-greenhouse-emissions-rise-third?CMP=twt_gu.

- December 30, 2013 – An analysis of fracking-related truck transportation in the Susquehanna River Basin in Pennsylvania found that greenhouse gas emissions from frack water and waste hauling operations were 70-157 metric tons of CO_2 equivalent per gas well.[1852]

- November 11, 2013 – In a letter to California Governor Jerry Brown, twenty of the nation's top climate scientists warned that pro-fracking policies will worsen climate disruption and harm California's efforts to be a leader in reducing greenhouse gas emissions. The letter called on Governor Brown to place a moratorium on fracking.[1853] On November 21, 2013, a group of Governor Brown's former policy and campaign advisors made a similar request in light of concerns about the effects of fracking on climate change and water pollution. [1854]

- October 18, 2013 – A team of researchers from multiple institutions including Harvard, the University of Michigan, and NOAA reported that methane emissions due to drilling activities in the south-central U.S. may be almost five times greater than reported by the world's most comprehensive methane inventory. "These results cast doubt on the US EPA's recent decision to downscale its estimate of national natural gas emissions by 25-30 percent," the authors wrote.[1855] As the *New York Times* reported, "The analysis also said that methane discharges in Texas and Oklahoma, where oil and gas production was concentrated at the time, were 2.7 times greater than conventional estimates. Emissions from oil and gas activity alone could be five times greater than the prevailing estimate."[1856]

- October 18, 2013 – A major study spearheaded by Stanford University's Energy Modeling Forum concluded that fracking and the shale gas revolution will have no long-term climate benefit. The study brought together a working group of about 50 experts and advisors from companies, government agencies, and universities, and modeling teams from 14 organizations. The study also found that build-out of infrastructure for fracking and natural gas will discourage efforts to conserve energy and boost efficiency. The study did not examine methane leaks in order to weigh in on the short-term climate impacts of natural gas.[1857]

[1852] Kevin R. Gilmore, Rebekah Hupp, and Janine Glathar, "Transport of Hydraulic Fracturing Water and Wastes in the Susquehanna River Basin, Pennsylvania," *Journal of Environmental Engineering* 140, no. 5 (2014), https://doi.org/10.1061/(ASCE)EE.1943-7870.0000810.
[1853] Paul Rogers, "Top Climate Scientists Call for Fracking Ban in Letter to Gov. Jerry Brown," *The Mercury News*, November 12, 2013, http://www.mercurynews.com/ci_24509392/top-climate-scientists-call-fracking-ban-letter-gov.
[1854] Sharon McNary, "Former Advisors to Gov. Brown Request Fracking Ban," *Southern California Public Radio*, November 21, 2013, http://www.scpr.org/blogs/politics/2013/11/21/15248/former-advisors-to-gov-brown-request-fracking-ban/.
[1855] Scot M. Miller et al., "Anthropogenic Emissions of Methane in the United States," *Proceedings of the National Academy of Sciences* 110, no. 50 (2013): 20018–22, https://doi.org/10.1073/pnas.1314392110.
[1856] Michael Wines, "Emissions of Methane in U.S. Exceed Estimates, Study Finds," *The New York Times*, November 25, 2013, http://www.nytimes.com/2013/11/26/us/emissions-of-methane-in-us-exceed-estimates-study-finds.html?_r=0.
[1857] Hillard Huntington, "Changing the Game? Emissions and Market Implications of New Natural Gas Supplies," *Energy Modeling Forum*, 2013, https://emf.stanford.edu/publications/emf-26-changing-game-emissions-and-market-implications-new-natural-gas-supplies.

- October 11, 2013 – As reported in the *Guardian*, key climate scientists argued that the growth in fracking across the United States is hurting the United States' credibility on climate change.[1858]

- October 2, 2013 – Updated measurements from the IPCC determined that methane is even worse for the climate than previously thought. The IPCC determined that methane is 34 times more potent as a greenhouse gas in the atmosphere than CO2 over a 100-year timeframe, and 86 times more potent over a 20-year timeframe.[1859]

- September 27, 2013 – The IPCC formally embraced an upper limit on greenhouse gases for the first time, warning that the world will exceed those levels and face irreversible climatic changes in a matter of decades unless steps are taken soon to reduce emissions. The IPCC reported that humanity faces a "carbon budget"—a limit on the amount of greenhouse gases that can be produced by industrial activity before irreversible, damaging consequences—of burning about a trillion metric tons of carbon. The world is on track to hit that by around 2040 at the current rate of energy consumption.[1860]

- August 12, 2013 – A *New Scientist* review of the science on fracking and global warming concluded that fracking could accelerate climate change rather than slow it.[1861]

- May 28, 2013 – A research team led by Jeff Peischl, an associate scientist at NOAA and the Cooperative Institute for Research in Environmental Sciences, estimated that methane leakage from Los Angeles-area oil and gas operations was about 17 percent.[1862, 1863]

- May 2013 – A group of scientists and journalists studying climate change, led by energy systems analyst Eric Larson of Princeton University and the news organization Climate Central, reported that the often-purported 50 percent climate advantage of natural gas over coal is unlikely to be achieved over the next three to four decades given methane leaks and other factors.[1864] The 50 percent claim is based on the fact that natural gas produces half as much carbon dioxide when burned than coal, but it ignores the significant greenhouse gas impacts of methane leakage that occurs throughout the life cycle of natural gas production, transmission, and distribution.

[1858] Bobby Magill, "Fracking Hurts US Climate Change Credibility, Say Scientists," *The Guardian*, October 11, 2013, http://www.theguardian.com/environment/2013/oct/11/fracking-us-climate-credibility-shale-gas.
[1859] Intergovernmental Panel on Climate Change, *Climate Change 2013 – The Physical Science Basis Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. T. F. Stocker et al. (Cambridge University Press, 2014).
[1860] Justin Gillis, "U.N. Climate Panel Endorses Ceiling on Global Emissions," *The New York Times*, August 12, 2013, http://www.nytimes.com/2013/09/28/science/global-climate-change-report.html?pagewanted=all.
[1861] Fred Pearce, "Fracking Could Accelerate Global Warming," *New Scientist*, August 12, 2013, http://www.newscientist.com/article/dn24029-fracking-could-accelerate-global-warming.html#.UpEWqsQ3uSo.
[1862] Jeff Peischl et al., "Quantifying Sources of Methane Using Light Alkanes in the Los Angeles Basin, California," *Journal of Geophysical Research: Atmospheres* 118, no. 10 (2013): 4974–90, https://doi.org/10.1002/jgrd.50413.
[1863] Stephanie Paige Ogburn, "Solving the Case of California's Extra Methane," *Scientific American*, May 15, 2013, sec. Environment, http://www.scientificamerican.com/article/solving-the-case-of-californias-extra-machine/.
[1864] Eric D. Larson, "Natural Gas & Climate Change" (Climate Central, May 2013), http://assets.climatecentral.org/pdfs/NaturalGas-and-ClimateChange.pdf.

- January 2, 2013 – A NOAA study found methane emissions from oil and gas fields in Utah to be as high as nine percent of production. These levels are considered extremely damaging to the climate.[1865]

- November 2012 – A review by the United Nations Environment Programme found that emissions from fracking, as well as other unconventional natural gas extraction methods, could increase global warming in the short-term and be comparable to coal over a 100-year timeframe.[1866]

- November 2012 – The International Energy Agency (IEA) found that a large natural gas boom—even with improvements in place to reduce leakage—would eventually lead to greenhouse gas concentrations of 650 parts per million and a global temperature rise of 3.5° C, far exceeding the 2° C limit which is critical to avoid the most severe effects of climate change.[1867]

- May 29, 2012 – The *Guardian* summarized a special report on natural gas by the IEA: "A 'golden age of gas' spurred by a tripling of shale gas from fracking and other sources of unconventional gas by 2035 will stop renewable energy in its tracks if governments do not take action."[1868]

- February 2012 – A study published in *Environmental Research Letters* found that the carbon dioxide emitted from the burning of natural gas —even neglecting the impacts of methane leakage—contributes significantly to greenhouse gas emissions that are driving climate change.[1869]

- February 7, 2012 – A NOAA study of Colorado gas fields measured methane emissions of about four percent, a significant percentage that could be very damaging to the climate.[1870]

- December 29, 2011 – As reported by the *New York Times,* levels of methane in the atmosphere have been steadily rising since 2007—coinciding with the onset of the fracking boom and posing a serious threat to the Earth's climate.[1871]

[1865] Tollefson, "Methane Leaks Erode Green Credentials of Natural Gas."
[1866] Pascal Peduzzi and Ruth Harding, "Gas Fracking: Can We Safely Squeeze the Rocks?" (United Nations Environment Programme Global Environmental Alert Service, 2012), Gas fracking: Can we safely squeeze the rocks?
[1867] World Energy Outlook, "Golden Rules for a Golden Age of Gas," Special Report (International Energy Agency, November 2012), https://www.iea.org/reports/golden-rules-for-a-golden-age-of-gas.
[1868] Fiona Harvey, "'Golden Age of Gas' Threatens Renewable Energy, IEA Warns," *The Guardian*, May 29, 2012, http://www.theguardian.com/environment/2012/may/29/gas-boom-renewables-agency-warns.
[1869] Nathan P. Myhrvold and Ken Caldeira, "Greenhouse Gases, Climate Change and the Transition From Coal to Low-Carbon Electricity," *Environmental Research Letters* 7, no. 1 (2012): 014019, https://doi.org/10.1088/1748-9326/7/1/014019.
[1870] Jeff Tollefson, "Air Sampling Reveals High Emissions From Gas Field," *Nature* 482 (2012): 139–40.
[1871] Justin Gillis, "The Puzzle of Rising Methane," *The New York Times*, December 29, 2011, http://green.blogs.nytimes.com/2011/12/29/the-puzzle-of-rising-methane/.

- October 2011 – A study from the National Center for Atmospheric Research concluded that substituting the use of natural gas for coal will increase, rather than decrease, the rate of global warming for many decades.[1872]

- July 6, 2011 – According to the U.S. Energy Information Administration and other research, significant amounts of methane are leaking from aging gas pipelines and infrastructure.[1873]

- April 2011 – A comprehensive analysis of the greenhouse gas footprint of natural gas from shale formations found that between 3.6 percent to 7.9 percent of the methane from natural gas production wells escapes into the atmosphere, rather than being combusted, thereby undermining any climate benefits of gas over coal as a source of energy.[1874, 1875]

[1872] Tom M. L. Wigley, "Coal to Gas: The Influence of Methane Leakage," *Climatic Change* 108 (2011): 601, https://doi.org/10.1007/s10584-011-0217-3.
[1873] Phil McKenna, "Thousands of Gas Leaks Under Boston and San Francisco," *New Scientist*, July 6, 2011, http://www.newscientist.com/article/mg21128203.800-thousands-of-gas-leaks-under-boston-and-san-francisco.html#.UpEbbMQ3uSp.
[1874] Robert W. Howarth, Renee Santoro, and Anthony Ingraffea, "Methane and the Greenhouse-Gas Footprint of Natural Gas From Shale Formations," *Climatic Change* 106 (2011): 679, https://doi.org/10.1007/s10584-011-0061-5.
[1875] Robert W. Howarth, Renee Santoro, and Anthony Ingraffea, "Venting and Leaking of Methane From Shale Gas Development: Response to Cathles et Al.," *Climatic Change* 113 (2012): 537–49, https://doi.org/10.1007/s10584-012-0401-0.

Threats from fracking infrastructure

The infrastructure for drilling and fracking operations is complex, widespread, and poses its own risks to public health and the climate. Beginning where silica sand is mined and processed and ending where gas is burned or liquefied for export, fracking infrastructure includes transmission pipelines, compressor stations, condensers, dehydrators, processing plants, LNG terminals, gas-fired power plants, distribution pipelines, and gas-fired appliances inside homes. Fracking infrastructure includes storage depots through which oil or gas is moved, filtered, pressurized, warehoused, refined, and vented. It also includes injection wells and recycling facilities that dispose and treat the prodigious amounts of liquid waste that fracking generates. Air pollution is produced at every stage of the process. [Note: harm from flare stacks is included in Air Pollution and is not taken up in the sub-sections that follow.]

Sand mining and processing

Silica sand is used as an ingredient in fracking fluid to prop open the cracks and fissures created during the hydraulic fracturing process in order to allow bubbles of gas or oil to escape the rock. By 2015, the United States had become the world's largest producer of sand for fracking operations, with 70 percent of domestic frack sand mined in Wisconsin and Minnesota.

In the Upper Midwest, this boom in silica sand mining threatens both air and water quality. It has transformed rural areas into industrialized zones and introduced complex public health risks and occupational health risks that are not well understood. Silica dust is a well-known cause of disabling and potentially fatal lung diseases, including both lung cancer and silicosis, and represents a proven occupational health threat to workers so exposed in other industries.

Inhalation exposures to silica dust can occur in several ways: during sandstone mining and loading operations; from truck traffic to and from mines and sand storage depots; during crushing, washing, and drying processes; and whenever dust is visible. Precise exposures to downwind communities remain uncertain. A 2018 study found elevated levels of particulate air pollution in ambient air near two Wisconsin industrial silica sand operations at levels that may pose health risks to nearby residents. Mining operations in Wisconsin and Minnesota are also sources of noise pollution, water contamination, and loss of property value. In January 2021, a county-wide ban on frack sand mining in Winona County, Minnesota was upheld by the U.S. Supreme Court.

By 2018, the center of U.S. frack sand mining had begun to shift from western Wisconsin to western Texas where sand mines in the Permian Basin have now become a major U.S. supplier of frack sand. Texas sand is considered inferior to Wisconsin sand, which is crush-resistant and ideally shaped to prop open fractures to allow oil and gas to flow up the borehole. However, Texas sand is up to 50 percent cheaper as it does not incur the cost of rail transport to reach the booming Permian Basin oil wells.

Like fracking itself, frack sand mining is a boom-and-bust industry that was hit hard by the downturn in oil and gas demand and crashing prices before and during the COVID-19 pandemic. In 2019-2020, silica sand mining companies in Wisconsin underwent a wave of bankruptcies, raising questions about whether the bonds set aside for mine restoration were sufficient. Although companies are responsible for returning their mines to farmland, prairie, or forest, the required bonds for the restoration work are sometimes backed up by subsidiary companies that may also go bankrupt.

Frack sand dust generated during fracking operations is a more complex mixture of respirable particles than crystalline silica alone. In 2020, a multi-part study led by the National Institute of Occupational and Environmental Health, examined frack sand dust toxicity on several organ systems and reported a wide range of harms. These are described below. For more on the health threats of frack sand to fracking workers, see also "Occupational health and safety hazards."

- November 15, 2022 – Wisconsin frack sand mining operations, which contracted during the 2020-2021 downturn in oil and gas extraction, rebounded in 2022, with some sand mines in southwestern Wisconsin reporting a more than 40 percent increase in sales.[1876]

- June 2, 2021 – In 2013, researchers with the National Institute for Occupational Safety and Health (NIOSH) published exposure assessment results for respirable silica dust among oil and gas workers conducting fracking operations. These results revealed, among other things, that occupational exposure limits for some fracking workers were being exceeded by a factor of ten. This paper describes the historical background of this research project, beginning in 2008 when NIOSH began a focused effort to understand the suite of occupational hazards among fracking industry workers that eventually led to the 2013 report. The authors also summarize the known risks of crystalline silica exposure for workers: lung cancer; chronic obstructive pulmonary disease; kidney disease; and incurable silicosis, which can either progress gradually or, in some cases, swiftly and fatally after only a few months of very intense exposure.[1877]

- May 24, 2021 – One of Wisconsin's biggest producers of sand for fracking, Hi-Crush Proppants, liquidated one of its four sand mines in the state after declaring bankruptcy last year.[1878]

- January 24, 2021 – The U.S. Supreme Court let stand a ban on the mining of sand for fracking operations in Winona County, Minnesota. The ban was first enacted in 2016 on the grounds that frack sand mining was incompatible with land stewardship and healthy

[1876] Rich Kremer, "Some Wisconsin Frac Sand Mines See Growing Demand from Oil, Natural Gas Companies," *Wisconsin Public Radio*, November 22, 2022, https://www.wpr.org/some-wisconsin-frac-sand-mines-see-growing-demand-oil-natural-gas-companies.
[1877] Eric J. Esswein, Bradley King, and Ryan Hill, "An Ancient Hazard in a 21st Century Workplace: The Power of Partnerships and Collaboration Investigating Respirable Crystalline Silica in Hydraulic Fracturing," NIOSH Science Blog, June 2, 2021, https://blogs.cdc.gov/niosh-science-blog/2021/06/02/oge-partnership/.
[1878] Rich Kremer, "Frac Sand Company Liquidating Western Wisconsin Mine," Wisconsin Public Radio, May 24, 2021, https://www.wpr.org/frac-sand-company-liquidating-western-wisconsin-mine.

communities. The ban was previously challenged by the industry in county and in state courts, both of which had upheld it.[1879]

- December 11, 2020 – A spate of lawsuits against frack sand mining operations in Wisconsin have targeted several proposed new mines as well as existing mines that have already been cited for multiple environmental violations, including spills of mine sludge into surface water and groundwater contamination.[1880]

- November 9, 2020 – Workers who service gas wells while they are being fracked are migratory, moving from one well pad to another after spending a few weeks at each well during the fracking stage. Because of the itinerant nature of their work, there is no registry of lung diseases in workers due to exposure to fracking sand dust. A multi-part investigation using a rat model attempted to understand whether inhalation of sand used at fracking sites could have adverse effects, even after short-term exposure bursts at concentrations that mimic those found at fracking well sites. This paper outlined the scope of the whole study. The organ systems studied included lungs, heart, kidney, brain, and the immune system. Cytotoxicity, inflammation, and molecular mechanisms were also explored. The findings showed that exposure to fracking sand dust has weaker biological effects than exposure to pure crystalline silica dust, but, nevertheless, harmful effects were seen across many organ systems even after short-term exposure.[1881]

- November 7, 2020 – As part of a multi-part investigation (see above), researchers studied the organ systems of rats exposed to fracking sand dust using an intratracheal instillation and inhalation exposure model in both living animals and in tissue studies. The major finding was that the toxicity of fracking sand dust extended to many organ systems—including the cardiovascular system, immune system, kidneys, and brain—which were harmed, for the most part, more severely than the lungs. The mechanism by which fracking sand provoked responses in organs distance from the lungs is not understood.[1882]

- October 22, 2020 – As part of a multi-part investigation (see above), researchers exposed rats to fracking sand dust and found changes in the brain. Specifically, acute inhalation of fracking sand dust altered the blood-brain barrier, elicited neuroinflammation, and caused changes in cells supporting the olfactory bulb, the hippocampus, and the cerebellum. The cerebellum also showed signs of synaptic injury.[1883]

[1879] Waterways Journal, "Supreme Court Upholds Winona Frac Sand Ban," *Waterways Journal*, January 24, 2021, https://www.waterwaysjournal.net/2021/01/24/supreme-court-upholds-winona-frac-sand-ban/.
[1880] Mike Tighe, "Suits Balloon Against Frac Sand Mining 'Running Amok,' Onalaska Lawyer Says," News8000.com, December 11, 2020, https://www.news8000.com/suits-balloon-against-frac-sand-mining-operations-running-amok-onalaska-lawyer-says/.
[1881] Jeffrey S. Fedan, "Biological Effects of Inhaled Hydraulic Fracturing Sand Dust. I. Scope of the Investigation," *Toxicology and Applied Pharmacology* 409 (2020), https://doi.org/10.1016/j.taap.2020.115329.
[1882] Stacey E. Anderson and Mark Barger, "Biological Effects of Inhaled Hydraulic Fracturing Sand Dust. IX. Summary and Significance," *Toxicology and Applied Pharmacology* 409 (2020), https://doi.org/10.1016/j.taap.2020.115330.
[1883] Krishnan Sriram et al., "Biological Effects of Inhaled Hydraulic Fracturing Sand Dust VII. Neuroinflammation and Altered Synaptic Protein Expression," *Toxicology and Applied Pharmacology* 409 (2020), https://doi.org/10.1016/j.taap.2020.115300.

- October 15, 2020 – As part of a multi-part investigation (see above), researchers compared the physico-chemicals properties of nine different samples of frack sand dust to pure respirable crystalline silica dust typically used in lab experiments. They also compared the pulmonary responses of rats exposed to both types of dust. The findings showed that both the physico-chemical characteristics and the biological effects of the two types of dust have distinct differences. Fracking sand dust samples had comparatively great amounts of non-silica minerals, the grains were less uniform in size, and the toxicity to lung tissue was less. Further, researchers documented significant differences in bioactivity among the various samples of frack sand dust.[1884]

- October 15, 2020 – As part of a multi-part investigation (see above), researchers examined the biological effects of inhaled fracking sand dust on the lung mechanics of laboratory rats. They found differences among nine different samples of dust collected at well pads during fracking operations. Some dusts caused temporary harm to various measures of breathing that appeared to resolve over time. A strong pro-inflammatory response, which is typical of silica dust exposure, was not evident in cases exposed to one of the nine different dust samples. However, the epithelial lining of the airways did show functional alterations.[1885]

- October 13, 2020 – In laboratory animals and humans alike, the deposition of silica dust in small airways of the lung, where they are ingested by macrophages, causes cell death and elicits dramatic and sustained inflammation. As part of a multi-part investigation (see above), researchers exposed rodent immune cells growing in culture to frack sand dust collected from a fracking site and looked for toxicity and inflammatory responses. The results confirmed that this particular sample of frack sand dust was toxic to mammalian lung cells, damaging their DNA and increasing inflammatory cytokine production.[1886]

- October 13, 2020 – As part of a multi-part investigation (see above), researchers examined the biological effects of inhaled fracking sand dust on the pulmonary inflammatory responses of laboratory rats and looked also for signs of toxicity and oxidative stress. Unexpectedly, the rats exposed via inhalation to frack sand dust showed only minimal signs of toxicity or changes in gene expression in their lung tissue. The researchers noted that the association of other minerals on the surfaces of the particles of this particular sample of frack sand dust may have "prevented, through masking, cellular interactions that would trigger an inflammatory response. It is of interest to determine whether frack sand dust collected from other hydraulic fracturing sites in the U.S. would,

[1884] Jeffrey S. Fedan et al., "Biological Effects of Inhaled Hydraulic Fracturing Sand Dust. II. Particle Characterization and Pulmonary Effects 30 d Following Intratracheal Instillation," *Toxicology and Applied Pharmacology* 409 (2020), https://doi.org/10.1016/j.taap.2020.115282.
[1885] Kristen A. Russ et al., "Biological Effects of Inhaled Hydraulic Fracturing Sand Dust. IV. Pulmonary Effects," *Toxicology and Applied Pharmacology* 409 (2020), https://doi.org/10.1016/j.taap.2020.115284.
[1886] Nicole S. Olgun et al., "Biological Effects of Inhaled Hydraulic Fracturing Sand Dust. III. Cytotoxicity and Pro-Inflammatory Responses in Cultured Murine Macrophage Cells," *Toxicology and Applied Pharmacology* 408 (2020), https://doi.org/10.1016/j.taap.2020.115281.

in this rat inhalation model, have a similar toxicity profile as the dust examined in the present study."[1887]

- September 30, 2020 – As part of a multi-part investigation (see above), researchers examined the biological effects of inhaled fracking sand dust on immune responses of exposed laboratory rats. They found several impacts. Exposure to fracking sand dust significantly altered lymph node cellularity and frequency of T-cells, B-cells, and natural killer cells, among other endpoints. These changes all signal impairment of immune functioning.[1888]

- September 12, 2020 – As part of a multi-part investigation (see above), researchers examined the biological effects of inhaled fracking sand dust on the cardiovascular of exposed laboratory rats. The results showed constriction of arteries, decreased heart rate, and alterations in blood pressure. Also, of expressions of proteins in kidney tissue were indicative of injury. "Thus, it appears that inhalation of fracking sand dust does have some prolonged effects on cardiovascular and, possibly, renal function."[1889]

- July 14, 2020 – Three companies mining silica sand for fracking declared bankruptcy in the five weeks preceding this report by the *Houston Chronicle*.[1890] One of those companies described holds over $953 million of assets but carries over $699 million of debt. The pandemic was cited as dramatically cutting demand and forcing the closure of silica mines across the United States.

- June 27, 2020 – Hi-Crush Inc. closed three of its four Wisconsin silica sand mines including its largest, as a result of reduced demand. The company told the *Wisconsin State Journal* that it had reduced its workforce by about 60 percent in the past three months.[1891]

- May 18, 2020 – An update on the Atlas Sand Company's frack sand conveyer belt project appeared in the *Permian Basin Oil and Gas Magazine*.[1892] The magazine reported that public scoping process of the Bureau of Land Management (BLM) for the 16.6-mile-long conveyor belt system for moving frack sand from West Texas into Southeast New Mexico had taken place, and the BLM was preparing an environmental assessment. The

[1887] Tina M. Sager et al., "Biological Effects of Inhaled Hydraulic Fracturing Sand Dust. V. Pulmonary Inflammatory, Cytotoxic and Oxidant Effects," *Toxicology and Applied Pharmacology* 408 (2020), https://doi.org/10.1016/j.taap.2020.115280.
[1888] Stacey E. Anderson et al., "Biological Effects of Inhaled Hydraulic Fracturing Sand Dust. VIII. Immunotoxicity," *Toxicology and Applied Pharmacology* 408 (2020), https://doi.org/10.1016/j.taap.2020.115256.
[1889] Kristine Krajnak et al., "Biological Effects of Inhaled Hydraulic Fracturing Sand Dust. VI. Cardiovascular Effects," *Toxicology and Applied Pharmacology* 406 (2020), https://doi.org/10.1016/j.taap.2020.115242.
[1890] Sergio Chapa, "Pandemic Forces 3 Frac Sand Companies into Chapter 11 Bankruptcy," *Houston Chronicle*, July 14, 2020, sec. Energy, https://www.houstonchronicle.com/business/energy/article/pandemic-forces-bankrupt-frac-sand-company-houston-15405869.php.
[1891] Chris Hubbuch, "Frac Sand Producer Hi-Crush Pursuing Bankruptcy amid Flagging Sales," *Wisconsin State Journal*, June 27, 2020, https://madison.com/wsj/business/frac-sand-producer-hi-crush-pursuing-bankruptcy-amid-flagging-sales/article_f0c4157d-1e2c-5ee4-a984-a33d0fdd7145.html.
[1892] PBOG, "Belting It Out," *Permian Basin Oil and Gas Magazine*, May 18, 2020, https://pboilandgasmagazine.com/belting-it-out/.

BLM was "analyzing a range of alternatives and its associated environmental effects," and, once the environmental assessment was complete, a 30-day public comment period would commence. (BLM published the assessment and opened the comment period on Aug. 28, 2020, accepting comments through Sept. 28, 2020.[1893]) The plan's developer claimed the project would lead to a 47 percent reduction per year in frack sand hauling trucks on public roadways. Trucking plays a role in the sand transfers within the new project, with the 140-acre offloading facility plan calling for 24 truck loading lanes. Proposed health and safety precautions in the proposal include a cover for the belt to decrease noise, and "environmental awareness training… to instruct personnel on the protection of cultural, ecological, and other natural resources."

- April 29, 2020 – Frack sand mining plants in Wisconsin laid off workers as oil prices crashed as the pandemic took hold. Sand from western Wisconsin "has the shape and composition to be widely used in the process of extracting oil and gas from shale rock," and the mines and layoffs are concentrated there.[1894]

- January 9, 2020 – The company behind the frack sand mine proposed in Kane County, Utah announced that it was "stepping away" from the project, "citing the conclusions of 'feasibility assessments,'" reported *KUER* radio.[1895] Southern Red Sands released the announcement together with Best Friends Animal Society, a national animal shelter organization sharing a border with the company's mining claim. The animal sanctuary had been one of the project's "most vocal opponents." Other expressions of opposition to the frack sand mine included a petition that garnered over 12,000 signatures.

- January 8, 2020 – The Atlas Sand Company sought to construct a 16.5-mile conveyor belt to carry silica sand for fracking, from an offloading facility in rural West Texas to a proposed 140-acre loadout facility in southeast New Mexico.[1896] The plan was submitted in January 2020 to the Bureau of Land Management, from which the project would need a permanent, 70-foot-wide right of way across federal land. The conveyer belt would be in place of trucking, the main method of transporting sand to well sites.

- July 7, 2019 – A company proposing a massive frack sand mine in southern Utah sought 1,200 acre-feet of water per year, which would be needed to process the sand. Residents and organizations, including an animal sanctuary, expressed alarm at the Kanab City

[1893] Bureau of Land Management, "The Bureau of Land Management Invites Public to Comment on Proposed Kermit Overland Conveyor Project | Bureau of Land Management," U.S. Department of the Interior, August 28, 2020, https://www.blm.gov/press-release/bureau-land-management-invites-public-comment-proposed-kermit-overland-conveyor.
[1894] Joe Taschler, "Oil Price Destruction Makes Its Way to Wisconsin's Frac Sand Mines," *Milwaukee Journal Sentinel*, April 29, 2020, https://www.jsonline.com/story/money/business/2020/04/29/wisconsin-frac-sand-plants-lay-off-workers-amid-oil-price-crash/3044935001/.
[1895] Fuchs, D. (2020, January 9). BREAKING: Divisive Southern Utah sand mine project will not move forward. *KUER.org.* Retrieved from https://www.kuer.org/energy-environment/2020-01-09/breaking-divisive-southern-utah-sand-mine-project-will-not-move-forward
[1896] Associated Press, "Company Eyes Texas-New Mexico Fracking Sand Transport System," *Albuquerque Journal*, January 8, 2020, sec. Business, https://www.abqjournal.com/1407811/company-eyes-texas-new-mexico-fracking-sand-transport-system.html.

Council's water service agreement near finalization. Those opposed also addressed truck traffic and harmful impacts on tourism, telling the *Salt Lake City Tribune*, "such an operation is not a good fit for a county so rich in geological scenery and steeped in agricultural traditions," and "authorities seem too eager to facilitate a proposal that could have far-reaching consequences and undermine the area's amenity-based economy."[1897] (See January 9, 2020 entry for an update addressing the cancellation of this project.)

- May 13, 2019 – As another Wisconsin frack sand company faced bankruptcy, an industry analyst said that many of the 128 silica mines in the state that supply oil and gas producers might have to close due to oversupply.[1898] "Maybe half of these mines, maybe as much as 75 percent of these mines, might need to be retired or just permanently reclaimed and then it brings up the question of is there enough money set aside for reclamation and restoration," the analyst told *Wisconsin Public Radio*. Though companies are responsible for returning the land to either farmland, prairie or forest, the analyst cast said that the required bonds for the restoration, "could be suspect," because they are backed up by subsidiary companies that may also go bankrupt.

- March 7, 2019 – The Minnesota Supreme Court announced that it would hear oral arguments on the legality of Winona County's ban on the mining of silica sand for use in fracking operations. A Winona County judge, as well as a Minnesota Court of Appeals, sided against Minnesota Sands, LLC and ruled in favor of the county legislature.[1899] The ban prohibits mining sand for industrial purposes but allows mining for construction purposes. The county has argued that it is within its rights to protect the health of its citizens. Its original ordinance, passed on November 22, 2016, was the first countywide ban in the nation on the extraction of silica sand for use in drilling and fracking operations. It became the subject of a lawsuit by Minnesota Sands on the grounds that the ordinance violates the federal Commerce Clause of the U.S. Constitution.[1900, 1901]

- December 27, 2018 – Wisconsin's frack sand mining industry had a volatile year in 2018. Mines that had closed in 2016 due to market downturns reopened on news of increased drilling activity. However, later in the year, the price for sand dropped dramatically as sand mines opened in Texas to serve fracking operations in the nearby Permian Basin.

[1897] Brian Maffly, "Worried about Truck Traffic and Losing Valuable Water, Southern Utah Residents Fight Plan to Mine Frack Sand," *The Salt Lake Tribune*, July 7, 2019, https://www.sltrib.com/news/environment/2019/07/07/worried-about-truck/.
[1898] Rich Kremer, "Frac Sand Producer In Wisconsin Faces Bankruptcy As Industry Shifts," *Wisconsin Public Radio*, May 13, 2019, https://www.wpr.org/frac-sand-producer-wisconsin-faces-bankruptcy-industry-shifts.
[1899] Winona Daily News Staff & Associated Press, "Challenge to Winona County's Frac Sand Ban to Be Heard by State Supreme Court next Month," *Winona Daily News*, March 7, 2019, https://www.winonadailynews.com/news/local/challenge-to-winona-county-s-frac-sand-ban-to-be/article_bd2474ea-e6a7-5f9f-8108-c957de307aad.html.
[1900] Chris Rogers, "Supreme Court Takes Frac Sand Case," *Winona Post*, October 31, 2018, https://www.winonapost.com/news/supreme-court-takes-frac-sand-case/article_2dd27a1a-e531-57d2-9be5-07297188b40e.html.
[1901] Dan Browning, "Appeals Court Upholds Winona County Ban on Frac Sand Mining," *Star Tribune*, July 30, 2018, https://www.startribune.com/minnesota-appeals-court-upholds-winona-county-ban-on-frac-sand-mining/489529801/.

Wisconsin sand companies then closed mines again, with one company laying off 37 employees.[1902]

- July 17, 2018 – As part of an industry-funded study, a research team retrospectively assessed the silica dust exposure among workers in the industrial sand industry, which includes sand used for fracking. Workers who went on to develop silicosis had significantly more exposure to silica dust than those who did not. Results showed decreases in exposure throughout the industry over time, driven in part by the establishment of workplace regulations in the 1970s that helped accelerate silica dust control programs. Adjustment for use of respiratory protection showed only modest reductions in estimated exposures.[1903]

- May 11, 2018 – The dunes sagebrush lizard in western Texas is imperiled because of booming demand for frack sand. "It's really a new threat and it just sort of came in all at once and really has the potential to wipe out a lot of lizard habitat, if not controlled," said a petition to the U.S. Fish and Wildlife Service that urged the agency to add the dunes sagebrush lizard to the endangered species list.[1904] Sand mines in the Permian Basin of west Texas now provide one quarter of the total U.S. supply of frack sand. Texas sand is up to 50 percent cheaper than Wisconsin sand as it does not incur the cost of rail transport to reach the booming Permian Basin oil wells, although it is considered inferior to Wisconsin sand, which is crush-resistant and ideally shaped to prop open fractures to allow oil and gas to flow up the borehole.[1905]

- March 12, 2018 – Significantly higher $PM_{2.5}$ levels than background were identified in ambient air around two Wisconsin industrial silica sand operations, by a team of University of Wisconsin-Eau Claire researchers led by environmental public health toxicologist and silica sand researcher Crispin Pierce.[1906] Average $PM_{2.5}$ concentrations found both above and below the EPA standard were likely due to: "site-specific considerations such as degree of year-round activity; proximity to other sand facilities; rail traffic; and differences between mining, processing, and transport activities." Average PM_{10} levels at both sites were above the State of California and WHO annual average standard. Though PM_{10} is not as closely associated with human health effects as the finer $PM_{2.5}$, and though required by Clean Air Act, the Wisconsin Department of Natural Resources has not collected $PM_{2.5}$. Authors concluded, "Given that no known

[1902] Rich Kremer, "2018 Was A Roller-Coaster Year For Wisconsin's Frac Sand Industry," *Wisconsin Public Radio*, December 27, 2018, https://www.wpr.org/2018-was-roller-coaster-year-wisconsins-frac-sand-industry.
[1903] Roy J Rando et al., "Retrospective Assessment of Respirable Quartz Exposure for a Silicosis Study of the Industrial Sand Industry," *Annals of Work Exposures and Health* 62, no. 8 (2018): 1021–32, https://doi.org/10.1093/annweh/wxy064.
[1904] Natalie Krebs, "In West Texas, Fracking Companies Face A Tough Challenger – The Dunes Sagebrush Lizard," *Texas Standard*, May 11, 2018, https://www.texasstandard.org/stories/in-west-texas-fracking-companies-face-a-tough-challenger-the-dunes-sagebrush-lizard/.
[1905] David Wethe, "Why This Sand From Texas Is Suddenly Worth $80 a Ton," *Bloomberg*, July 10, 2018, https://www.yahoo.com/news/why-sand-texas-suddenly-worth-134140942.html.
[1906] Crispin Pierce et al., "Monitoring of Airborne Particulates near Industrial Silica Sand Mining and Processing Facilities," *Archives of Environmental & Occupational Health* 74, no. 4 (2019): 185–96, https://doi.org/10.1080/19338244.2018.1436036.

level of particulate exposure is considered harmless, that risk has been established down to at least 5 µg/m3, and that statistically significant increases in $PM_{2.5}$ were measured in this study, health risks may be increased for residents around frac sand facilities."

- August 7, 2017 – A University of Iowa team evaluated the impact of frack sand mining and processing on the concentration of particulate matter in the air of surrounding communities. Sampling in 17 homes located within 800 meters from sand mining activities, the team found that, overall, particulate matter and silica concentrations were lower than regulations and guidelines established to prevent silicosis but spiked when winds blew over the facility. They concluded that particulate matter levels from fracking sand mining and processing were "unlikely to cause chronic adverse health conditions." Sampling for this study, which took place in 2014, did not consider the impact of living near multiple adjacent frack sand operations. The industry in western Wisconsin has expanded considerably since that time.[1907]

- November 25, 2017 – In Minnesota, a district judge upheld Winona County's ban on the mining, processing, and loading of frack sand. In her decision, the judge referenced public health and safety threats, fragility of the water quality in the area, and evidence for harm from sand mines in other areas. Winona is the first county in the United States to pass a countywide ban on frack sand extraction. Efforts to replicate the ban are now ongoing in neighboring counties.[1908, 1909]

- July 5, 2016 – The Wisconsin Department of Natural Resources (DNR) released a *Strategic Analysis for Public Review* of the state's industrial sand mining industry that downplayed environmental health effects from air pollution. There are 128 industrial sand mine facilities in Wisconsin, including the mines themselves and processing and rail loading facilities. The DNR identified airborne particulate matter as a primary concern for industrial sand mining facilities and said that air quality monitors in western Wisconsin have not detected a problem.[1910] Researchers, organizations, and the native community involved in monitoring impacts of the frack sand industry challenged these findings, pointing to lack of data collection on the most dangerous kind of particulate matter called PM2.5, which represents fine particles that are less than 2.5 microns in width. These critics noted that the U.S. Environmental Protection Agency (EPA) had previously expressed concerns about the DNR's approach to regulating PM2.5.[1911]

[1907] Thomas M. Peters et al., "Community Airborne Particulate Matter from Mining for Sand Used as Hydraulic Fracturing Proppant," *Science of The Total Environment* 609 (2017): 1475–82, https://doi.org/10.1016/j.scitotenv.2017.08.006.

[1908] Matt McKinney, "Judge's Ruling on Winona County Ban of Frac Sand Mining Stirs Interest," *Minneapolis Star-Tribune*, November 25, 2017, https://web.archive.org/web/20171126004240/https://www.startribune.com/judge-s-ruling-on-winona-county-frac-sand-ban-stirs-interest/459974433/.

[1909] Chris Rogers, "District Court Upholds County Frac Sand Ban," *Winona Post*, November 22, 2017, https://www.winonapost.com/news/district-court-upholds-county-frac-sand-ban/article_4778c8d2-290b-5644-ab0d-7b608a482be1.html.

[1910] Wisconsin Department of Natural Resources, "Industrial Sand Mining in Wisconsin Strategic Analysis for Public Review," 2016, https://dnr.wi.gov/topic/EIA/documents/ISMSA/ISMSA.pdf.

[1911] Chris Hubbuch, "DNR Releases Frac Sand Analysis to Immediate Criticism from Environmental Group," *La Crosse Tribune*, July 6, 2016, https://lacrossetribune.com/news/local/dnr-releases-frac-sand-analysis-to-immediate-criticism-from-environmental-group/article_bce8ea56-fff1-52ae-97cb-c67cfb120a1f.html.

Regarding groundwater, the report described elevated levels of several metals in wastewater holding ponds at the sand mines, presenting a risk to groundwater quality.

- March 25, 2016 – The Occupational Safety and Health Administration (OSHA) amended its existing standards for occupational exposure to respirable crystalline silica, "having determined that employees exposed to respirable crystalline silica at the previous permissible exposure limits face a significant risk of material impairment to their health."[1912] Key provisions include the reduction of the permissible exposure limit to 50 micrograms per cubic meter of air, averaged over an 8-hour shift. The standards cover many industries with some having two years to comply; the hydraulic fracturing industry is allowed an additional five-year extension for engineering controls, until June 23, 2021.[1913] The *New York Times* reported that safety experts have advocated for a tightening of silica exposure standards for the past forty years but that "progress was stymied for decades by resistance from affected companies and regulatory inaction." The article reported that many oil and gas companies in particular were not meeting the current silica exposure standard. The new rules, when fully in effect, are estimated to save 600 lives and prevent 900 new cases of silicosis per year.[1914]

- March 1, 2016 – University of Wisconsin anthropologist Thomas Pearson conducted in-depth interviews examining the impact of frack sand mining on sense of community, quality of life, and place in nearby residents. His findings indicated that the sudden influx of this heavy extractive industry has eroded residents' sense of place and belonging and that these experiences are rarely taken into account by policymakers. Residents report "significant anxiety and stress from truck traffic, noise, light pollution, and uncertainty about environmental health impacts," and distress caused by drastic changes to long-familiar landscapes over which they have no control. Pearson concluded that policymakers should pay closer attention to the uneven distribution of benefits and costs and "recognize that the costs go beyond quantifiable economic or environmental impacts."[1915]

- January 29, 2016 – The Institute for Wisconsin's Health, Inc. released its Health Impact Assessment (HIA) on frack sand mining operations in western Wisconsin, prepared with the participation of 15 local and tribal health departments. According to the report, the HIA was a collaborative effort. The scope of the report was limited to the potential for community-level health effects of industrial sand mining in western Wisconsin. Regarding air quality, the report concluded that health effects from the impact of

[1912] Occupational Safety and Health Administration, "Occupational Exposure to Respirable Crystalline Silica," March 25, 2016, https://www.federalregister.gov/documents/2016/03/25/2016-04800/occupational-exposure-to-respirable-crystalline-silica.
[1913] Occupational Safety and Health Administration, "OSHA's Final Rule to Protect Workers from Exposure to Respirable Crystalline Silica," Final Rule, March 25, 2016, https://www.osha.gov/laws-regs/federalregister/2016-03-25-1.
[1914] Barry Meier, "New Rules Aim to Reduce Silica Exposure at Work Sites," *The New York Times*, March 24, 2016, sec. Business, https://www.nytimes.com/2016/03/24/business/new-rules-aim-to-reduce-silica-exposure-at-work-sites.html.
[1915] Thomas W. Pearson, "Frac Sand Mining and the Disruption of Place, Landscape, and Community in Wisconsin," *Human Organization* 75, no. 1 (2016): 47–58, https://doi.org/10.17730/0018-7259-75.1.47.

industrial sand mining on community-level air quality related to particulate matter are unlikely, and that it was also unlikely that community members would be exposed to respirable crystalline silica from industrial sand mining as currently regulated. Regarding water quality, the report concluded that contamination is possible; however, health effects were unlikely. Quality of life effects were likely, but variable.[1916] Though it was a "Level 1 Partner" for the report, the Ho-Chunk Nation responded to the HIA with criticism, writing, "we are disappointed with the conclusions drawn in the report, particularly in the section on air quality impacts, and we believe a more robust assessment of the air quality impacts is required before such conclusions can be drawn." They wrote that the HIA failed to provide an accurate and complete analysis of the health threats posed by this industry because of the limited scope, and "minimal discussion about fine particulate matter (or PM2.5), which likely presents the biggest threat from industrial sand mining operations.[1917] As reported by Rochester, Minnesota's *Post-Bulletin*, Crispin Pierce, director of University of Wisconsin-Eau Claire's environmental public health program, "believes the study ignored important air quality data collected by university students at sand mining sites at Bloomer, New Auburn and Augusta during the past 18 months," which he described as "the only work that looked at these fine particles."[1918]

- November 6, 2015 – According to findings from a pilot study led by Crispin Pierce (see entry above), levels of fine particulate matter (PM2.5) are not being adequately measured near frack sand operations. Air monitors set up by Pierce and his team consistently showed higher readings than detections measured by Wisconsin's DNR.[1919] In some instances, PM2.5 levels exceeded the EPA guideline of 12 micrograms per cubic meter of air. In an accompanying news story, Pierce noted that the state's air quality data largely comes from industry itself. "'The DNR so far has continued to shy away from doing their own monitoring,' he said. 'The monitoring I've seen so far is inadequate. People aren't looking at PM2.5, and they really should be—from unbiased sources.'"[1920]

- October 15, 2015 – *Inside Climate News* reported on the response of nearby communities to the "bust" cycle of the frack sand industry in Wisconsin and Minnesota. Reactions reported included ongoing concerns that the industry does not provide permanent economic prosperity. Municipalities and community organizations are using the lull to advance protections in advance of a possible upturn: "Towns in the region are also trying to strengthening their local zoning ordinances, such as adding rules to limit industrial

[1916] A. Boerner, N. Young, and D. Young, "Health Impact Assessment of Industrial Sand Mining in Western Wisconsin" (Institute for Wisconsin's Health, Inc., 2016), https://www.heartland.org/_template-assets/documents/publications/iwhi_industrial_sand_hia.pdf.
[1917] Ho-Chunk Nation, "Concerns about Air Quality Impacts and Human Health Remain After Release of Industrial Sand Mining Health Impact Assessment," News Release, March 9, 2016, http://midwestadvocates.org/assets/resources/Frac%20Sand%20Mining/20160309HoChunkHIARelease.pdf.
[1918] E. Lindquist, "Report Downplays Frac Sand Link to Health Troubles," *Post-Bulletin*, February 4, 2016, http://www.postbulletin.com/news/local/report-downplays-frac-sand-link-to-health-troubles/article_b3023c6c-fe74-5028-a7a4-6238fa035eaa.html.
[1919] Kristin Walters et al., "PM 2.5 Airborne Particulates Near Frac Sand Operations," *Journal of Environmental Health* 78, no. 4 (2015): 8–12.
[1920] Ryan Schuessler, "Wisconsin Locals Fear Dust from Mines for Fracking Sand Even as Boom Wanes," *Al Jazeera America*, 2015, http://america.aljazeera.com/articles/2015/11/6/wisconsin-locals-fear-frac-sand-mining.html.

noise and light pollution. In other cases, communities are trying to oust pro-sand advocates from office."[1921]

- June 30, 2015 – Because the amount of sand used per fracking well has increased, demand for silica sand by the oil and gas industry is still growing even though new drilling activity has taken a downturn. A global investment bank reported that fracking operations now require an average of 4.2 million pounds of sand per well. A few years ago, silica sand comprised 9.5 percent of fracking fluid but now is closer to 20 percent. Further "rising intensity" of sand use is expected.[1922]

- June 15, 2015 – An investigative report by *EnergyWire* documented self-reported health impacts among residents of southwestern Wisconsin who live near silica sand mining operations that service the fracking industry. Exposure to silica dust is a proven cause of silicosis and lung cancer. (See further entries on silica sand exposure among workers in the section, "Occupational Health and Safety Hazards.") Residents near frack sand mine operations reported exposure to dust pollution and respiratory problems. Air monitoring data from the Wisconsin DNR showed that none of the state's 63 active sand mines were in violation for particulate matter, but, as the author noted, the state measured particles only 10 micrometers in diameter or larger.[1923] Below this diameter, crystalline silica particles are small enough to bypass the body's natural clearance mechanisms and are likely to lodge deep in the lungs where they can initiate scarring, autoimmune reactions, and tumor formation.[1924]

- May 28, 2015 – The U.S. Geological Survey reviewed the geological and economic status of sand mining for hydraulic fracturing operations in the United States. More the 70 percent of the sand used in U.S. fracking operations originates from the Upper Midwest, especially in Wisconsin and Minnesota, where an ongoing sand mining surge has paralleled the national fracking boom. More than 40 different operators are involved in the mining, processing, transportation, and distribution of frac sand to a fast-growing domestic market. U.S. frack sand is also exported and shipped throughout the world.[1925]

[1921] Zahra Hirji, "In Fracking Downturn, Sand Mining Opponents Not Slowing Down," *Inside Climate News*, October 15, 2015, https://insideclimatenews.org/news/15102015/fracking-struggles-sand-mining-opponents-momentum-minnesota-wisconsin/.
[1922] Sergio Chapa, "Demand For Sand: Frac Sand Use per Well Goes up amid Low Oil Prices," *San Antonio Business Journal*, June 30, 2015, https://www.bizjournals.com/sanantonio/blog/eagle-ford-shale-insight/2015/06/demand-for-sand-frac-sand-use-per-well-goes-up.html.
[1923] Pamela King, "Frac Sand Towns Question Whether Rules Protect Them Against Silica Pollution," *E&E News*, June 15, 2015, https://web.archive.org/web/20150621073016/http://www.eenews.net/stories/1060020192.
[1924] U.S. Department of Labor, "Dust and Its Control," 1987, https://web.archive.org/web/20111018032206/https://www.osha.gov/dsg/topics/silicacrystalline/dust/chapter_1.html.
[1925] Mary Ellen Benson, Anna B. Wilson, and Donald L. Bleiwas, "Frac Sand in the United States: A Geological and Industry Overview" (U.S. Geological Survey, May 2015), https://pubs.er.usgs.gov/publication/ofr20151107.

Pipelines and compressor stations

More than 300,000 miles of natural gas transmission pipelines traverse the United States. They are serviced, every 40 to 100 miles, by compressor stations that maintain the pressure of the gas flowing through them. (Pump stations do the same for oil pipelines.)

Pipelines and compressor stations are significant sources of air pollutants, including benzene and formaldehyde, constituting potential health risks to those living nearby while offering no economic benefits. Instead, they are associated with loss of tax revenue and economic development for the communities where they are sited. A 2017 study identified 70 different air pollutants in compressor station emissions. A 2019 study found that 39 of the chemicals released are linked to cancer. A 2020 study found that proximity to higher amounts of volatile emissions from compressor stations were linked with higher death rates. A 2021 study found "alarming levels" of volatile organic compounds, including cancer-causing benzene, in the indoor air of homes located near a compressor station in Ohio.

Pipelines and compressor stations vent methane into the atmosphere as part of routine maintenance operations and represent a climate risk. Historically, the Federal Energy Regulatory Commission (FERC), which undertakes environmental reviews of proposed pipelines, has not considered climate impacts in its approval process. In 2021, the Commission signaled that it would begin considering greenhouse gas emissions as part of its permitting requirements but did not settle on a method for doing so.

Pipelines and compressor stations are also accident-prone. The Medical Society of the State of New York, the Massachusetts Medical Society, and the American Medical Association have each called for comprehensive health impact assessments regarding the health and safety risks associated with natural gas pipelines, which include fires, explosions, and leaks.

In addition to transmission pipelines, 450,000 miles of gathering lines carry raw oil and gas from the wellheads to collection and processing sites within the United States. These smaller-diameter, lower-pressure pipelines are regulated lightly or, in rural areas, not at all. In some cases, large, high-pressure gas pipelines legally qualify as gathering lines and so remain exempt from regulations despite their size. More than one-third of the nation's gathering lines are in Texas. In 2018, three gathering line explosions in Texas' Permian Basin killed several people, including a three-year-old child, and badly burned others. Nevertheless, in October 2019, the Texas Railroad Commission, which oversees oil and gas extraction in Texas, rejected a proposal to subject the state's rural gathering lines to regulation and set safety protocols.

A 2021 nationwide study found that gathering and transmission pipelines are disproportionately sited in socially vulnerable communities, especially Indigenous communities.

A 2022 study of methane emissions from natural gas gathering pipelines in the Permian Basin found leakage rates 14-52 times higher than the U.S. EPA's national estimate for gathering

lines and 4-13 times higher than the highest estimate derived from ground-based surveys. High-emitting pipelines were responsible for a large part of these aggregate emissions.

Distribution pipelines, which carry gas into individual homes and businesses, are an overlooked but significant source of methane emissions and a cause of urban tree death, according to emerging research. In October 2018, a Columbia Gas work crew in Massachusetts' Merrimack Valley over-pressurized a natural gas distribution system while replacing aging pipelines and triggered 80 simultaneous natural gas explosions, killing one teenager, injuring 23 people, destroying or damaging 130 buildings, prompting a mass evacuation, and costing the company over $1 billion.

- June 4-6, 2023 – Extreme heat and cold can cause oil and gas pipelines to corrode, deform, and fracture, raising safety concerns. A North Dakota State University modeling study and literature review investigated how extreme air temperatures influence the distribution of temperatures along oil and gas pipelines buried underground and, specifically, sought to characterize soil thermal conductivity. The results showed that the heat transfer rate of soil is modulated by depth, moisture, density, soil types, and wind speed, as well as air temperature.[1926]

- May 18, 2023 – Gas pipelines are required by law to be externally covered with a crack-resistant coating to protect against corrosion. The coatings of pipelines stored above ground for more than six months can become compromised by sun exposure, becoming less ductile and more prone to corrosion. A commentary on sun-exposed pipelines argues that many pipeline companies are essentially using expired materials, flouting federal regulations.[1927]

- November 15, 2022 – A report on 20-year trends in pipeline incidents by the U.S. Department of Transportation's Pipeline and Hazardous Materials Safety Administration found that pipeline failures caused deaths every year during the past two decades. Between 2002-2021, gas pipeline incidents caused at least 1,000 injuries and 227 fatalities.[1928]

- November 8, 2022 – A simulation study of leakage from gas pipelines located in urban areas looked at explosion and disaster risk under different wind speeds. The researchers found that wind speed has a great influence on the concentration and distribution of gas leakage and diffusion. The higher the wind speed, the more diffusion of gas and the smaller the overpressure peak. When a fire occurs, higher wind speeds sweep flames horizontally, endangering objects further away. When an explosion occurs, lower wind

[1926] Ying Huang et al., "Weather Impact On Pipeline Temperature Distribution," in *The 8th International Conference on Civil, Structural and Transportation Engineering*, 2023, https://doi.org/10.11159/iccste23.162.
[1927] Bill Kitchen, "Pipeline Companies Use Expired Materials to Cut Costs, Flouting Regulations," *Truthout*, May 18, 2023, https://truthout.org/articles/pipeline-companies-use-expired-materials-to-cut-costs-flouting-regulations/.
[1928] Pipeline Hazardous Materials Safety Administration, "Pipeline Incident 20 Year Trends," Pipeline and Hazardous Materials Safety Administration, November 15, 2022, https://www.phmsa.dot.gov/data-and-statistics/pipeline/pipeline-incident-20-year-trends.

speeds produce an oscillation shock wave that is more intense, and the duration of the explosion is longer.[1929]

- October 4, 2022 – Using aerial measurements, a study of methane emissions from natural gas gathering pipelines in the Permian Basin calculated a leakage rate of between 2.7 and 10 megagrams (Mg) methane per year per kilometer of pipeline, with high-emitting pipelines responsible for a large part of the aggregate emissions. This estimate is 14-52 times higher than the EPA's national estimate for gathering lines, and 4-13 times higher than the highest estimate derived from a ground-based survey of gathering lines. "Our results suggest that pipeline emissions are underestimated in current inventories and highlight the importance of a large sample size when calculating basin-wide pipeline emission factors." Serviced by compressor stations, gathering lines ferry natural gas from wells to processing plants or directly to distribution pipelines. Because they are typically located underground and in remote locations, distribution pipelines are more difficult to monitor, and they are notoriously underregulated. The authors note that the Pipeline and Hazardous Materials Safety Administration (PHMSA) has issued a rule to expand regulatory oversight of gathering pipelines, establishing annual and incident reporting requirements for all 700,000 kilometers (435,000 miles) of natural gas gathering lines in the United States, and requiring leak survey and repair requirements for more than 30,000 kilometers (18,600 miles) of gathering pipelines. This rule took effect in May 2022 although some provisions will not be enforced until 2024. "We recognize this development as a point of forward progress; however, the results from this study imply a need for increased pipeline-specific leak detection and repair programs that account for the heavy-tailed nature of the emissions distribution."[1930]

- October 3, 2022 – Using publicly available, industry-sourced data from the Federal Energy Regulatory Commission (FERC), researchers evaluated hazardous air pollutants found in five high-pressure natural gas transmission pipelines. These pollutants represent a diverse array of naturally occurring compounds that are entrained in natural gas along with methane. The results showed detectable concentrations of hazardous air pollutants (HAPs) in all five pipelines, with benzene showing the highest median concentrations. Contaminants also included hydrogen sulfide, toluene, xylene, ethylbenzene, and mercury. This study represents the first analytical assessment of this class of air pollutants within the U.S. transmission pipeline system. "By determining the concentrations of HAPs associated with transmission pipeline natural gas and associate emissions sources, this study provides a rational foundation for health-based risk assessments of emissions events from transmission infrastructure including fugitive emissions, venting or blowdowns, and loss of containment events….These data can be

[1929] Dai Wang et al., "Research on Natural Gas Leakage Diffusion of Urban Underground Pipeline and Its Explosion Hazard," *KSCE Journal of Civil Engineering* 27, no. 2 (February 2023): 590–603, https://doi.org/10.1007/s12205-022-1795-5.
[1930] Jevan Yu et al., "Methane Emissions from Natural Gas Gathering Pipelines in the Permian Basin," *Environmental Science & Technology Letters*, October 4, 2022, acs.estlett.2c00380, https://doi.org/10.1021/acs.estlett.2c00380.

utilized to estimate air quality impacts and health risks that could result from exposure to natural gas when emitted to the atmosphere.[1931]

- September 7, 2022 – A nationwide study of leaks from underground natural gas pipelines found that soil conditions can affect the migration behavior of the escaping gas. Soil moisture was the dominant influence on gas concentration and spreading distance. Wetter soil reduced diffusion and increased concentrations near the leak point. Drier soils allowed the gas to spread further. The authors attributed the pipeline leaks in this study primarily to material failure (51.4 percent) and corrosion (43.2 percent). "The study did not capture all factors necessary to understand the dynamics of subsurface gas transport and nearby atmospheric transport."[1932]

- July 29, 2022 – In February 2022, FERC revised its 1999 pipeline policy to address climate concerns, and then subsequently retreated from those reforms in the face of industry opposition. A legal analysis of FERC's decision-making on new pipeline proposals urges commissioners to prioritize the growing number of state and federal policies that mandate a transition to renewable energy. These policies determine whether a pipeline can be said to have "project need" under Section 7 of the Natural Gas Act. Failing to consider the climate impacts of pipelines is a failure to prevent burdening the ratepaying public with stranded fossil fuel assets. Also, FERC's failure to adequately address project need for pipelines arguably also violates Sections 4 and 5 of the Natural Gas Act, which require FERC to ensure that rates, charges, practices, and rules governing natural gas sales and transportation are 'just and reasonable.' FERC can no longer put to the side the clean energy transition underway in the United States and relegate the climate impacts of pipelines to a subsidiary 'environmental' assessment separate and apart from project need. Instead, because of developing local, state, and federal policies on climate change and the clean energy transition, the environmental impacts of new fossil fuel pipelines are central to whether new pipelines are in the present or future public convenience and necessity."[1933]

- July 20, 2022 – A Chinese research team proposed a life cycle method for evaluating carbon emissions from natural gas pipelines that takes into account four stages: manufacturing, construction, operation, and recycling. They then applied this method to three case studies of built natural gas pipelines in China. The team found that 80 percent of CO2 emissions are attributable to the first stage, which includes steel manufacturing. Pipeline length, diameter and wall thickness each influence related CO2 emissions. Leakage from compressor stations during pipeline operation are a leading source of

[1931] Curtis L Nordgaard et al., "Hazardous Air Pollutants in Transmission Pipeline Natural Gas: An Analytic Assessment," *Environmental Research Letters* 17, no. 10 (October 1, 2022): 104032, https://doi.org/10.1088/1748-9326/ac9295.
[1932] Younki Cho et al., "A Closer Look at Underground Natural Gas Pipeline Leaks across the United States," *Elementa: Science of the Anthropocene* 10, no. 1 (September 7, 2022): 00095, https://doi.org/10.1525/elementa.2021.00095.
[1933] Alexandra B. Klass, "Evaluating Project Need for Natural Gas Pipelines in an Age of Climate Change," Law & Economics Working Papers (University of Michigan Law School, 2022), https://repository.law.umich.edu/law_econ_current/238.

methane emissions, as is leakage from the pipeline itself. The aggregate methane leakage was equivalent to the total lifecycle CO2 emissions.[1934]

- July 15, 2021 – Two former pipeline inspectors became whistleblowers about hazards on an ethane pipeline carrying the highly volatile liquid from Marcellus Shale fracking wells in Ohio, Pennsylvania, and West Virginia to a new Shell petrochemical plant. Investigative reporting that relied on heavily redacted documents obtained through Freedom of Information Act requests documented several serious safety charges in the whistleblower complaint. Among the most serious are compromised pipeline coatings, a problem that increases the risk of corrosion. According to Pipeline and Hazardous Materials Safety Administration (PHMSA), corrosion is the cause of about 18 percent of pipeline accidents. Although the Shell contractors on the project fired the inspectors and the Occupational Safety and Health Administration (OSHA) dismissed the complaint, PHMSA investigators had, prior to the whistleblower complaint, "found that Shell had inadequate procedures for the company's inspectors to detect coating damage and other problems." The investigation documented a culture of clique behavior among the industry's inspectors—hired and paid by the industry—that effectively encouraged overlooking expensive problems but which the terminated inspectors, who are appealing OSHA's dismissal, had resisted.[1935]

- June 23, 2021 – The U.S. Court of Appeals for the District of Columbia Circuit, denied a certificate for the Spire STL pipeline in a strong opinion that criticized the Federal Energy Regulatory Commission (FERC) for failing to determine whether there was a need for the 65-mile natural gas pipeline from Illinois to Missouri. The previous year, FERC Chairman Richard Glick reopened a review of its Certificate Policy Statement, which dictates the process for determining whether a proposed pipeline is in the public interest and should therefore be approved. The federal court's ruling may have an impact on this review. However, there are precedent agreements that have historically been viewed by the commission as a proxy for pipeline need. Glick, who voted against FERC's 2019 decision to approve the Spire STL pipeline, has criticized the reliance on precedent agreements, particularly in cases where project applications only include agreements between affiliated companies.[1936]

- June 13, 2021 – Responding to community concerns, a research team investigated the relationship between proximity to a natural gas compressor station in eastern Ohio's Jefferson County and health risks to residents. The results showed that concentrations of volatile organic compounds (VOCs) were indeed elevated in the air inside of homes closer to the compressor station and had reached "alarming levels." Cancer-causing

[1934] Siyuan Xu et al., "Life Cycle Assessment of Carbon Emission from Natural Gas Pipelines," *Chemical Engineering Research and Design* 185 (September 2022): 267–80, https://doi.org/10.1016/j.cherd.2022.07.018.
[1935] Mike Soraghan, "Whistleblowers Say 'Bad Seeds' Undermine Pipeline Safety," *E&E News*, July 15, 2021, https://web.archive.org/web/20210715124012/https://www.eenews.net/articles/whistleblowers-say-bad-seeds-undermine-pipeline-safety/.
[1936] Niina H. Farah, Mike Soraghan, and Miranda Willson, "Court's 'Historic' FERC Slap-Down Shifts Pipeline War," *E&E News*, June 23, 2021, https://web.archive.org/web/20210623133723/https://www.eenews.net/stories/1063735583.

benzene was 2-17 times higher in homes located fewer than two kilometers from the compressor. Other VOCs were also detected in elevated quantities near the compressor and validated the residents' concerns. Authors recommended further study to explicate the specific pathways of exposure.[1937]

- June 3, 2021 – The Danish Environmental Protection Agency halted work on the Denmark of Baltic Pipe, a pipeline connecting Poland with Norwegian gas fields, and temporarily withdrew an environmental permit because of concerns over the impact on protected mice and bat species. The initial study had provided insufficient information on protection of the animals.[1938]

- June 1, 2021 – Using a questionnaire administered to pipeline operators, asset managers, and industry regulators in Nigeria, researchers determined the challenges to "Nigerian Pipeline Integrity Management Systems." Pipeline leaks result in environmental damage and economic loss. The results described in this peer-reviewed study showed that management plans are poorly implemented and that most pipeline failures were due to: forces such as corrosion, weather, and aging; human errors such as poor operation; and willful damage and vandalism. Authors found multiple reasons for the lack of effective implementation of pipeline integrity management in Nigeria. These included "shoddy" repair of pipelines and ancillary facilities, lack of management commitment to safety, high costs of pipeline integrity management procedures, and poor management of data.[1939]

- May 18, 2021 – As part of nationwide study, a research team found that people living in U.S. counties where gas infrastructure is located are at greater risk of exposure to water and air pollution, public health and safety issues, and other negative impacts. Further, counties with more socially vulnerable populations, especially Indigenous populations, had significantly higher densities of gathering and transmission pipelines than counties with less socially vulnerable populations. "Assuming natural gas gathering and transmission pipelines continue to be built, decision-makers and the general public should keep in mind that the network is already distributed inequitably with respect to social vulnerability, and that future projects can either maintain the inequitable status quo or shift the distribution in ways that will potentially exacerbate or ameliorate current disparities."[1940] The study's lead author said to *North Carolina Health News,* "This is what the communities themselves have been saying for a long time… For the first time,

[1937] Kaitlin A. Vollet Martin et al., "Survey of Airborne Organic Compounds in Residential Communities Near a Natural Gas Compressor Station: Response to Community Concern," *Environmental Advances* 5 (2021), https://doi.org/10.1016/j.envadv.2021.100076.
[1938] Reuters, "Concern Over Wildlife Halts Building of Norway-Poland Gas Link," Reuters, June 3, 2021, https://www.reuters.com/business/energy/denmark-halts-baltic-pipe-project-after-environmental-permit-withdrawn-2021-06-03/.
[1939] Sunday Kyrian Nsude et al., "Failures in Natural Gas Pipeline Systems: An Assessment of Pipeline Integrity Management Programs from Nigeria," *International Journal of Scientific Engineering and Applied Science* 7, no. 6 (2021), http://ijseas.com/volume7/v7i6/IJSEAS202106105.pdf.
[1940] Ryan E. Emanuel et al., "Natural Gas Gathering and Transmission Pipelines and Social Vulnerability in the United States," *GeoHealth* 5 (2021), https://doi.org/10.1029/2021GH000442.

we gathered all of this together and zoomed out and took a national look and said, 'You know what, these pipelines don't exist in a vacuum.'"[1941]

- March 19, 2021 – The Department of the Interior's Bureau of Safety and Environmental Enforcement (BSEE) has oversight of the approximately 8,600 miles of active offshore oil and gas pipelines located on the seafloor of the Gulf of Mexico. However, it does not have a robust oversight process for ensuring the integrity of these pipelines. BSEE has authorized industry to leave over 97 percent (about 18,000 miles) of all decommissioned pipeline mileage on the Gulf of Mexico seafloor since the 1960s. Further, if pipelines decommissioned-in-place are later found to pose risks, there is no funding source for removal. "GAO recommends that BSEE take actions to further develop, finalize, and implement updated pipeline regulations to address long-standing limitations regarding its ability to (1) ensure active pipeline integrity and (2) address safety and environmental risks associated with pipeline decommissioning. Interior agreed with this recommendation."[1942]

- March 19, 2021 – Following a certificate from FERC to begin operations at the Enbridge compressor station in Weymouth, Massachusetts, two incidents resulted in emergency shutdowns and large gas releases from the facility, at least one of them caused by equipment malfunction. Long-standing public opposition to the facility reflects concern about risks to public health and safety in this urban environment, environmental justice violations, and greenhouse gas emissions. In apparent response to this public pressure, the Commission voted in February 2021 to establish a "paper briefing process," a type of official comment period which has the goal of answering specific unresolved questions. This decision appeared to signal a rare instance of a willingness by the Commission to reexamine the approval of a facility already in service. More than 60 entities applied to be "intervenors," or participants, in this proceeding. On the side opposing the Enbridge compressor, applicants responded to this unusual "second chance," and the possibility of a FERC reversal of authorization for the project. Pediatric environmental health researcher Philip Landrigan, MD, said, "All of these groups are joining together and they're catalyzed by the recognition that a very poor job was done in the health impact assessment several years ago. There's a real opportunity against the background of this incomplete piece of work to overturn the decision." Brita Lundberg, MD, of Greater Boston Physicians for Social Responsibility said, "FERC specifically asked about what safety and environmental justice issues we know about now that we did not know about when the project was approved. … I find it a very hopeful sign that FERC is now offering to listen. … There is still the opportunity to do the right thing."[1943]

[1941] Greg Barnes, "New N.C. State Study Finds Socially Vulnerable Communities Bear Brunt of Pipelines," *North Carolina Health News*, June 2, 2021, https://www.northcarolinahealthnews.org/2021/06/02/new-n-c-state-study-finds-socially-vulnerable-communities-bear-brunt-of-pipelines/.
[1942] U.S. Government Accountability Office, "Offshore Oil and Gas: Updated Regulations Needed to Improve Pipeline Oversight and Decommissioning" (U.S. Government Accountability Office, March 19, 2021), https://www.gao.gov/products/gao-21-293.
[1943] Miriam Wasser, "Why A Federal Order in The Weymouth Compressor Case Has the Natural Gas World Worried," WBUR, March 19, 2021, https://www.wbur.org/news/2021/03/19/weymouth-compressor-ferc-precedent-enbridge-natural-gas.

- March 4, 2021 – Tracking methane emissions from pipelines has largely focused on structural defects and fugitive emissions. However, these sources are underestimates, as revealed by high resolution satellite monitoring that can capture episodic, intentional methane releases, including venting.[1944]

- February 24, 2021 –Members of the Massachusetts congressional delegation asked federal regulators to reconsider their decision to allow the Enbridge compressor station in Weymouth to go into service. "The site is located within a half mile of Quincy Point and Germantown – 'environmental justice communities' that suffer persistent environmental health disparities due to socioeconomic and other factors – as well as nearly 1,000 homes, a water treatment plant and a public park," the legislators wrote in the letter. "An estimated 3,100 children live or go to school within a mile of the site, and more than 13,000 children attend school within three miles of the compressor station."[1945]

- February 14, 2021 – A study tested whether key demographic and socioeconomic characteristics of a neighborhood's population—racial composition, educational attainment, poverty rate, and rurality—are associated with the probability of a proposed pipeline running through it. The study addressed planned natural gas transmission pipelines in the United States for which researchers were able to discover proposed routes, combined with 2015 census data. It found only limited, and sometimes contradictory evidence of environmental injustice regarding these proposed pipelines. It is not clear whether systemic inequalities in environmental hazards hold true for existing pipelines, as their precise routes are kept confidential by the industry and the federal government, and therefore cannot be studied in this way. The study responded to the environmental justice community's calls for an assessment of the environmental risks caused by the development of gas infrastructure, and whether those risks are equally distributed within the population. Authors of this study emphasized that their results "cannot be used as a verdict over the equity of specific pipelines without considering local contexts and group-specific experiences of marginalization." They also stated that more realistic models are needed, that risks may go beyond the census tract of the pipeline, and that the study lacks precision in the large census tracts.[1946]

- February 5, 2021 – The Coastal GasLink project, a $6.6-billion pipeline designed to carry natural gas, continued, with more than 140 kilometers of pipe laid in northern British Columbia toward a $40-billion LNG terminal on the province's North Coast for export to Asia. Although the hereditary Wet'suwet'en chiefs still oppose the pipeline, their priorities have shifted to caring for their elders during the pandemic. In British Columbia's north, First Nations people have been disproportionately hit with COVID-19,

[1944] European Space Agency, "Monitoring Methane Emissions from Gas Pipelines," Phys.org, March 4, 2021, https://phys.org/news/2021-03-methane-emissions-gas-pipelines.html.
[1945] Jessica Trufant, "Lawmakers Push Regulators to Reexamine Compressor Approval," *The Patriot Ledger*, February 24, 2021, https://www.patriotledger.com/story/news/2021/02/24/lawmakers-push-regulators-reexamine-compressor-approval/4555468001/.
[1946] Johann Strube, Brian C. Thiede, and Walter E. "Ted" Auch, "Proposed Pipelines and Environmental Justice: Exploring the Association between Race, Socioeconomic Status, and Pipeline Proposals in the United States," *Rural Sociology*, 2021, https://doi.org/10.1111/ruso.12367.

with double the confirmed cases compared to the rest of the population. There have also been outbreaks among industry employees and that has slowed construction.[1947]

- February 4, 2021 – Because of violations for erosion and sedimentation control, the Mountain Valley Pipeline has paid over a half a million dollars in fines by consent order of the West Virginia Department of Environmental Protection. Altogether there were 29 notices issued, and some of them contained multiple violations.[1948]

- February 3, 2021 – Natural gas pipelines have proliferated throughout Appalachia's Marcellus Shale region. In West Virginia alone, natural gas production increased four-fold in the past decade. Survey research on the effects of pipeline development in rural Appalachia found that residents live with the fear of disasters, toxic contamination, explosions, construction noise, and the anxiety of having no control over their own land.[1949]

- February 1, 2021 – Global Energy Monitor identifies, maps, describes, and categorizes oil and gas pipelines, and liquified natural gas (LNG) terminals throughout the world. Its online database, Global Fossil Infrastructure, shows that $1 trillion in capital expenditures are on a collision course with commitments by most large economies to transition to carbon neutrality by mid-century, representing risks for stranded assets. United States, as the world's leading developer of pipelines, is at particular risk, as is natural gas infrastructure in general: 18 of the 20 longest pipelines in development and 82.7 percent of all pipelines in development globally carry natural gas. Currently, only four major financial institutions have restricted investments in pipelines. At the same time, opposition from landowners, indigenous groups, and climate activists is causing the cancellation or delay of high-profile pipelines and is changing perceptions of pipelines as a good investment. "Closing the midstream policy gap at financial institutions is key to mitigating the effects of climate change and the increasing risk that, in a decarbonizing world, many of these midstream assets will soon be stranded."[1950]

- January 19, 2021 – Natural gas compressor stations emit loud, low-frequency noise that travels hundreds of meters and is audible to birds. A study that investigated its effects on bird reproduction introduced a recorded playback of compressor noise into nest boxes of eastern bluebirds and tree swallows. The authors measured reproductive output and success, including the number of eggs per nest, the proportion of eggs that hatched, the proportion of young that fledged, as well as proportion of eggs that produced fledglings.

[1947] Betsy Trumpener, "A Year After Wet'suwet'en Blockades, Coastal GasLink Pipeline Pushes on Through Pandemic," *CBC*, February 5, 2021, https://www.cbc.ca/news/canada/british-columbia/coastal-gaslink-pipeline-bc-wet-suwet-en-pandemic-1.5898219.
[1948] Laurence Hammack, "Mountain Valley Pipeline Cited Again for Erosion and Sedimentation Violations," *The Roanoke Times*, February 4, 2021, https://roanoke.com/news/local/mountain-valley-pipeline-cited-again-for-erosion-and-sedimentation-violations/article_496c5fd4-671c-11eb-a913-8b3e7d176b2b.html.
[1949] Erin Brock Carlson and Martina Angela Caretta, "Living with Natural Gas Pipelines: Appalachian Landowners Describe Fear, Anxiety and Loss," *The Conversation*, February 3, 2021, https://theconversation.com/living-with-natural-gas-pipelines-appalachian-landowners-describe-fear-anxiety-and-loss-152586.
[1950] James Browning et al., "Pipeline Bubble 2021: Tracking Global Oil and Gas Pipelines" (Global Energy Monitor, February 2021), https://globalenergymonitor.org/report/pipeline-bubble-2021/.

Incubation rates were lower in noisy boxes for both bluebirds and tree swallows. Also, for both species, the noise reduced hatching success by 9–15 percent compared to quiet boxes.[1951] A summary article reported that "compressor noise caused behavioral changes that led to reduced reproductive success for eastern bluebirds and tree swallows. The results indicate … that natural gas infrastructure can create an 'equal-preference ecological trap,' where birds do not distinguish between lower and higher quality territories, even when they incur reproductive costs."[1952]

- August 1, 2020 – A Michigan Technological University team collected publicly available fuel and emissions data from the entire extraction, transport, and combustion lifecycle to determine that oil and gas pipelines have the highest total embedded carbon emissions. Their method, introduced in this paper, considers all the emissions that a facility enables rather than only what it emits at a point-source, as conventional methods do. This "bottleneck method" showed that the top ten CO_2 emission bottlenecks in the U.S. are predominantly oil (47 percent) and natural gas (44 percent) pipelines.[1953] Commenting on their findings, the researchers expressed surprise at the large emissions contribution from natural gas. "For natural gas, the biggest emissions came from pipeline transport. The sheer length of pipelines—the Transcontinental Gas Pipeline (Transco) alone branches into more than 16,900 kilometers (10,500 miles) of pipeline from Texas to New York—means there are lots of places to emit gas."[1954]

- July 31, 2020 – In early May 2020, a cloud of methane 12 miles wide and drifting over five counties in Florida was picked up in an analysis of satellite data. For more than two months, its source remained a mystery until the state's Department of Environmental Protection confirmed that three hundred metric tons of methane had been intentionally released from a compressor station near Gainesville during an emergency shutdown. The facility is part of the Florida Gas Transmission Pipeline, a joint venture between Energy Transfer and Kinder Morgan.[1955]

- July 20, 2020 – The Dakota Access pipeline was ordered to cease operations by a federal judge after a ruling found that the U.S. Army Corps of Engineers had violated the National Environmental Policy Act in permitting it. In the same month, the lesser-known Tesoro High Plains pipeline was also ordered shut down for the first time in its 67 years of operation after a determination that the pipeline was trespassing on Native American

[1951] Danielle P. Williams et al., "Experimental Playback of Natural Gas Compressor Noise Reduces Incubation Time and Hatching Success in Two Secondary Cavity-Nesting Bird Species," *Ornithological Applications* 123 (2021): 1–11, https://doi.org/10.1093/ornithapp/duaa066.
[1952] Jeff Mulhollem, "Songbirds' Reproductive Success Reduced by Natural Gas Compressor Noise," PennState News, February 18, 2021, https://news.psu.edu/story/647898/2021/02/18/research/songbirds-reproductive-success-reduced-natural-gas-compressor-noise.
[1953] Alexis S. Pascaris and Joshua M. Pearce, "U.S. Greenhouse Gas Emission Bottlenecks: Prioritization of Targets for Climate Liability," *Energies* 13, no. 15 (2020), https://doi.org/10.3390/en13153932.
[1954] Sarah Derouin, "The Surprising Source of Greenhouse Gas Emissions," *Eos*, March 1, 2021, https://eos.org/articles/the-surprising-source-of-greenhouse-gas-emissions.
[1955] Naureen S. Malik, "Florida Offers Pipeline Clue in Mystery of Giant Methane Leak - Bloomberg," *Bloomberg*, July 31, 2020, https://www.bloomberg.com/news/articles/2020-07-31/florida-offers-pipeline-clue-in-mystery-of-giant-methane-leak.

land.[1956] Together, the two pipelines ship over a third of fracked crude from the Bakken shale formation to market. "Their travails signal the ebbing of the oil industry's sway in the U.S. heartland and underscore the growing heft and savvy of challengers who've become emboldened to demand higher compensation and safeguards."

- July 17, 2020 – Subsidence and the development of sinkholes have occurred alongside pipeline construction for the transport of natural gas liquids from the Marcellus Shale fields in western Pennsylvania to an export terminal in Delaware County. Sunoco's Mariner East pipeline development had "catastrophic" potential, according to the state's Public Utility Commission in 2018, though they later changed that determination. Pipeline leaks of natural gas liquids can be more dangerous than methane leaks because the liquids turn into gases once they escape. Heavier than air, these gases then sink to the ground rather than dissipate, are highly volatile, and can easily explode.[1957]

- June 30, 2020 – The D.C. Circuit Court ruled that the Federal Energy Regulatory Commission (FERC) can no longer use "tolling orders" to prevent opponents of proposed pipeline projects from going to court while the Commission considers their appeals while allowing construction to proceed.[1958] Under the Natural Gas Act, landowner opponents of pipelines must file a petition at FERC and wait for the Commission to resolve it before going to court, which it must do within 30 days. But the agency routinely issues so-called tolling orders to extend that review period indefinitely while land seizures and construction often move forward. The DC Circuit Court decision coalesced around a simple conclusion: The Natural Gas Act didn't give FERC the authority to issue tolling orders and stall litigation.

- June 27, 2020 – A gas pipeline crew drilling horizontally under the Blanco River in Texas' Hill Country spilled 36,000 gallons of drilling fluid into the Trinity Aquifer, contaminating at least six water wells drawing from it. Reporting on the incident three months following, the *Houston Chronicle* interviewed residents whose wells were contaminated, including those who had opposed the 30-mile Permian Highway fracked gas pipeline from the time of its announcement. Those interviewed reported challenges for maintaining personal hygiene during the pandemic, dependency on bottled water, and startling results from water testing that turned up detections of arsenic, lead, and other metals at levels beyond maximum allowable concentrations in public drinking water supplies. Ultimately, Kinder Morgan offered to install a rainwater collection system on the properties. Some of the property owners have gone on to sue the company for

[1956] Catherine Ngai, "A Pipeline Is Quietly Ordered Shut in New Signal of Shale's Woes," *Bloomberg Green*, July 20, 2020, https://www.bloomberg.com/news/articles/2020-07-20/another-oil-pipeline-ordered-shut-signals-shale-s-woes.
[1957] Susan Phillips, "More Sinkholes Develop alongside Mariner East Construction in Chester County," *State Impact Pennsylvania*, July 17, 2020, https://stateimpact.npr.org/pennsylvania/2020/07/17/mariner-east-pipeline-construction-site-of-additional-sinkholes-in-chester-county/.
[1958] Ellen M. Gilmer, "'Kafkaesque' FERC Pipeline Process Needs Revamp, Court Says (3)," *Bloomberg Law*, June 30, 2020, https://news.bloomberglaw.com/environment-and-energy/kafkaesque-pipeline-review-process-needs-revamp-court-rules.

"injecting contaminants, including a 'cocktail of carcinogens,' into the aquifer that feeds their wells."[1959]

- June 25, 2020 – Satellite data is now being used by companies, academic researchers, and some energy producers to find large methane leaks.[1960] For example, energy consultancy Kayrros recently observed a leak spewing 93 metric tonnes of methane every hour from the Yamal pipeline that carries gas from Siberia to Europe. Kayrros said its analysis of the satellite data showed concentrations of methane around compressor stations along the pipeline. According to *Reuters*, satellite discoveries of methane leaks could also lead to "more stringent regulatory regimes targeting natural gas, once seen as a 'clean' fossil fuel, as governments seek to combat climate change."

- June 21, 2020 – New Jersey Natural Gas stopped work on its pipeline in Monmouth County following an "inadvertent return, or the unintended discharge of drilling mud to the surface through a natural crack or fissure in the bedrock being drilled."[1961] This inadvertent return damaged a home and flooded its basement by sending drilling mud into a fissure leading to the home's foundation. A statement from the homeowner read, "I was almost too terrified to investigate after what had felt like an explosion in my house… I discovered huge cracks in my foundation, my basement floor, and even my walls. As I watched in horror water and sludge came pouring in through the cracks, I ran to the construction site and begged them to stop." The sludge also flowed into a nearby stream. A 2018 lawsuit to overturn the pipeline's approvals was still pending in the Appellate Division of State Superior Court.

- June 19, 2020 – In Michigan, the Canadian company Enbridge reported additional damage to its Line 5 pipeline running through the Straits of Mackinac. That line has since been shut down. The damage included a damaged screw anchor support that had shifted from its original position, 150 feet from spots on the pipeline where protective coating had worn away, according to the Governor's office. The Michigan Attorney General's office issued a statement saying, "Yet again, Enbridge has confirmed what we already know—Line 5 is a clear and present danger to our Great Lakes and to the millions of Michiganders who rely on those lakes for recreation, business and tourism."[1962]

- June 10, 2020 – Using data collected from an advanced mobile leak detection (AMLD) platform in twelve metropolitan areas, a research team estimated methane emissions from local gas distribution systems. An historically underreported source of greenhouse gases,

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[1959] Jay Root, "A Pipeline Poisons the Wells in Hill Country," *Houston Chronicle*, June 27, 2020, sec. Investigations, https://www.houstonchronicle.com/news/investigations/article/A-pipeline-poisons-the-wells-in-Hill-Country-15371071.php.
[1960] Shadia Nasralla, "Satellites Reveal Major New Gas Industry Methane Leaks," *Reuters*, June 25, 2020, sec. Environment, https://www.reuters.com/article/us-climatechange-methane-satellites-insi-idUSKBN23W3K4.
[1961] Steve Strunsky, "Drilling Work Halted on Natural Gas Pipeline after Mishap Damages N.J. Couple's House," *NJ.Com*, June 21, 2020, sec. Burlington, https://www.nj.com/burlington/2020/06/work-halted-on-natural-gas-pipeline-after-drilling-sludge-damages-nj-couples-house.html.
[1962] Melissa Frick, "Enbridge Reports 'Significant Damage' on Line 5 Pipeline to State," *MLive.Com*, June 20, 2020, sec. News, https://www.mlive.com/news/2020/06/enbridge-reports-significant-damage-on-line-5-pipeline-to-state.html.

distribution pipelines are the low-pressure network of service lines that carry natural gas into individual homes and business. The results of this study fill in an important data gap as most recent national assessments of methane emissions from the US gas supply chain did not take local gas distribution systems into account at all. The team found that the age and the material of the pipelines and their interaction affected leakage rate. Overall, emissions were far greater than those of previous studies. The mean of their emissions estimates was 0.55 teragrams of CO_2 equivalent per year, a value 3.85 times greater than the current EPA estimate.[1963]

- May 26, 2020 – A 30-inch diameter gas pipeline that runs between southern Mississippi and Pennsylvania exploded in Kentucky in August 2019, killing one person and injuring several others. A Pipeline Hazardous Materials Safety Administration (PHMSA) investigation found that the company had missed evidence of defects in the pipeline in 2011, the year of its last inspection. The pipeline is operated by Texas Eastern Transmission LP, a subsidiary of Enbridge.[1964]

- May 14, 2020 – The nation's gathering pipelines that carry raw natural gas from the wellhead to processing plants are served by gathering stations, each of which includes a compressor along with associated separators and tanks. Many include dehydrators, which remove water from the gas, and equipment to remove hydrogen sulfide gas and other contaminants. In a study funded by the oil and gas industry, a research team estimated the collective methane emissions from the nation's 5,200 gathering stations by compiling 85 hours of data from a representative sample of 180 stations, as provided to them by industry partners. Measurements were taken using optimal gas imaging cameras and Bacharach Hi Flow samplers. The team reported a 45 percent lower mean methane emissions rate than a previous study, likely because the gathering stations included in the current study were smaller and lower throughput. The authors argue that their sample was more representative of the gathering station population nationally. Their results also showed that the whole gas emission rates from the components on gathering stations were comparable to, although somewhat higher than, emission factors used by EPA's greenhouse gas reporting program. However, when the activity data of the gathering stations were factored in, the study's estimate of total methane emissions (1,290 gigagrams/year) was just 66 percent of the current estimates used in the EPA's Greenhouse Gas Inventory (1,955 gigagrams/year). The authors propose a replicable method that incorporates activity data to update emissions estimates from gathering stations. The field data and the EPA data together show that significantly more methane was released from gathering stations as part of normal operations (venting, flaring, compressor exhaust, maintenance blowdowns) than via accidental fugitive leaks from equipment.[1965]

[1963] Zachary D. Weller, Steven P. Hamburg, and Joseph C. von Fischer, "A National Estimate of Methane Leakage from Pipeline Mains in Natural Gas Local Distribution Systems," *Environmental Science & Technology* 54, no. 14 (2020): 8958–67, https://doi.org/10.1021/acs.est.0c00437.
[1964] Bill Estep, "Report: Gas Pipeline in Fatal Kentucky Explosion Had Defects Operator Had Not Found," *Lexington Herald Leader*, May 26, 2020, https://www.kentucky.com/news/state/kentucky/article242995236.html.
[1965] Daniel Zimmerle et al., "Methane Emissions from Gathering Compressor Stations in the U.S.," *Environmental Science & Technology* 54, no. 12 (2020): 7552–61, https://doi.org/10.1021/acs.est.0c00516.

- May 10, 2020 – Proximity to higher amounts of non-methane volatile organic compound (VOC) emissions from natural gas pipeline compressor stations were linked to higher death rates in a national, county-level ecological study.[1966] Twelve specific VOCs were also associated with significantly higher mortality rates, including styrene, 2,2,4-trimethylpentane, ethylene dichloride, and vinyl chloride. Studies of human health impacts from compressor stations have been almost completely absent from the literature, despite the expansion of natural gas infrastructure. The Indiana University team also found that counties with compressor station emissions had higher percentages of Hispanic populations and lower percentages of non-Hispanic White populations. Authors concluded that the "results of the current study, along with findings from other research, challenge the conventional wisdom that natural gas is a clean fuel that we may rely on to provide for our energy needs with little adverse effect."

- May 7, 2020 – When a Beaver County home was destroyed in a 2018 explosion, pipeline company ETC Northeast Pipeline LLC, a subsidiary of Energy Transfer, was fined a record $30 million. Subsequently, the Pennsylvania Department of Environmental Protection has issued hundreds of additional construction violation notices on the same pipeline for infractions such as slipping slopes along the pipeline route, failed erosion and sedimentation barriers, and sediment-laden water getting into streams, all violations of the company's clean water permits.[1967]

- April 27, 2020 – Public concerns about Kinder Morgan's storage of pipeline segments for the 428-mile Permian Highway Pipeline led to an investigative report by Austin, Texas radio station KXAN.[1968] Residents had noticed coated pipe segments lying out in the open despite manufacturer warnings that the epoxy coatings can degrade with prolonged exposure to sunlight. KXAN's investigation found no existing regulations that govern pipe coating exposure to UV radiation.

- April 17, 2020 – The proposed Northeast Supply Enhancement (NESE) pipeline would bring fracked gas from Pennsylvania to Long Island at a cost of a billion dollars. A report by the Institute for Energy Economics and Financial Analysis (IEEFA) described the lack of need for the gas and the significant cost to ratepayers in four New York boroughs. The report lead author called the proposal "unwise and high-risk with ratepayers expected to bear the brunt of the cost."[1969]

[1966] Michael Hendryx and Juhua Luo, "Natural Gas Pipeline Compressor Stations: VOC Emissions and Mortality Rates," *The Extractive Industries and Society* 7, no. 3 (2020): 864–69, https://doi.org/10.1016/j.exis.2020.04.011.
[1967] Reid Frazier, "The Revolution Pipeline Explosion Resulted in a Huge Fine for Energy Transfer. Now, DEP Says It's Found Hundreds of New Violations," *State Impact Pennsylvania*, May 7, 2020, https://stateimpact.npr.org/pennsylvania/2020/05/07/the-revolution-pipeline-explosion-resulted-in-a-huge-fine-for-energy-transfer-now-dep-says-its-found-hundreds-of-new-violations/.
[1968] Jody Barr, "PIPELINE EXPOSED: KXAN Investigation Uncovers Safety Concerns over Pipes Used in Kinder Morgan's Permian Highway Pipeline," *KXAN Austin*, April 27, 2020, https://www.kxan.com/investigations/pipeline-exposed-kxan-investigation-uncovers-safety-concerns-over-pipes-used-in-kinder-morgans-permian-highway-pipeline/.
[1969] Suzanne Mattei and Tom Sanzillo, "Proposed NESE Gas Pipeline May Stick New York Ratepayers with One Billion-Dollar+ Cost," *Institute for Energy Economics & Financial Analysis*, April 17, 2020, https://ieefa.org/ieefa-report-proposed-nese-gas-pipeline-may-stick-nys-ratepayers-with-one-billion-dollar-cost/.

- April 8, 2020 – A Nuclear Regulatory Commission (NRC) report concluded the Indian Point Energy Center nuclear power plant would remain safe even in case of a rupture on a nearby, newly installed 42-inch gas transmission pipeline.[1970] The study called a rupture "unlikely" and stated that even if one were to occur, "the nuclear power plant would remain protected." The study team, composed of NRC and external experts, did however criticize earlier "optimistic assumptions in analyzing potential rupture" and recommended follow up actions, stating, "**The NRC needs to improve its processes and practices for technical reviews, inspection support, petition reviews, pipeline analysis, and coordination with other agencies.**" (Emphasis in original.)[1971] Environmental groups expressed dissatisfaction with the NRC conclusion that "maintain(s) the status quo."[1972]

- April 3, 2020 – A study that investigated natural gas leaks and tree deaths found that fugitive methane exposure from leaky natural gas distribution systems threatens urban tree canopies. Researchers measured methane and oxygen concentrations in subsurface soil at the base of case (dead or dying) trees and control (healthy) trees in Chelsea, Massachusetts. About 25 percent of dead trees had increased methane in their base soil, as opposed to one percent of healthy trees. The research team found the greatest soil methane concentrations on the side of the tree pit closest to the street, nearest to where natural gas distribution pipelines are located, suggesting that "elevated soil methane may contribute to urban street tree decline and that the fugitive methane may be the result of leaking pipeline infrastructure beneath the street surface."[1973]

- March 19, 2020 – An x-ray technician working on the Mariner East pipeline in Pennsylvania was charged with fraud for falsifying documents recording x-rays of pipeline welds.[1974] The worker allegedly certified in writing that the welds had been properly x-rayed and were acceptable when these certifications were false. He eventually pled guilty in federal court.[1975] The Mariner East pipeline carries natural gas liquids, which can cause a catastrophic explosion if they leak.

[1970] U.S. Nuclear Regulatory Commission (NRC Staff, "Report of the U.S. Nuclear Regulatory Commission Expert Evaluation Team on Concerns Pertaining to Gas Transmission Lines Near the Indian Point Nuclear Power Plant," April 8, 2020, https://www.nrc.gov/docs/ML2010/ML20100F635.pdf.
[1971] Jeremy Dillon, "NRC Says Gas Pipeline Doesn't Pose Threat to Indian Point," *E&E News*, April 15, 2020, https://web.archive.org/web/20200423075240/https://www.eenews.net/eenewspm/2020/04/15/stories/1062883415.
[1972] Thomas C. Zambito, "NRC Says Gas Pipeline No Threat to Indian Point, Dashing Hopes for Shutdown by Groups," *The Journal News*, April 20, 2020, https://www.lohud.com/story/news/local/indian-point/2020/04/20/nrc-gas-pipeline-indian-point-reactors/5166749002/.
[1973] Claire Schollaert et al., "Natural Gas Leaks and Tree Death: A First-Look Case-Control Study of Urban Trees in Chelsea, MA USA," *Environmental Pollution* 263 (2020): 114464, https://doi.org/10.1016/j.envpol.2020.114464.
[1974] Susan Phillips, "Mariner East Worker Charged with Falsifying Documents Related to a Pipeline Weld," *State Impact Pennsylvania*, March 19, 2020, https://stateimpact.npr.org/pennsylvania/2020/03/19/mariner-east-worker-charged-with-falsifying-documents-related-to-a-pipeline-weld/.
[1975] Department of Justice U.S. Attorney's Office Western District of Pennsylvania, "Radiograph Technician on Natural Gas Pipeline Admits Falsifying Testing Results," Press Release, June 22, 2020, https://www.justice.gov/usao-wdpa/pr/radiograph-technician-natural-gas-pipeline-admits-falsifying-testing-results.

- March 9, 2020 – Residents living a quarter-mile from a compressor station in rural Washington County, Pennsylvania told the Pittsburgh *Post-Gazette* that the persistent low-frequency sound from the station "gives them headaches and feels like torture."[1976] The township does not regulate low-frequency noise. A member of the same family was recently diagnosed with multiple myeloma, a blood plasma cancer linked to benzene and other pollutants. This compressor station emitted 1.2 tons of benzene in 2018, "making it the third biggest source of the carcinogen in the seven-county southwestern Pennsylvania region," according to data obtained from the Pennsylvania Department of Energy Emissions Inventory. Washington County has 40 compressor stations pushing gas through the pipelines.

- February 13, 2020 – NRC's Office of Inspector General conducted an inquiry into NRC's hazard analysis of a natural gas pipeline then proposed to run through the grounds of the Indian Point nuclear power plant. The inquiry found that the NRC failed to properly analyze the safety impact of a potential rupture of that pipeline and did not provide an appropriate response to "relevant and on point" stakeholder concerns.[1977] Congresswoman Nita Lowey and Westchester County Executive George Latimer expressed disappointment and outrage about these failures. "NRC must immediately explain to our communities the risks they face as a result of the agency's faulty processes and take steps to protect the public from any dangers that have resulted from the pipeline's approval and installation," the congresswoman stated.[1978]

- December 3, 2019 – In a "first-of-its-kind dispute," a pipeline operator sued the Texas Railroad Commission, which regulates oil and gas drilling, over approval of gas flaring.[1979] Dallas-based Exco Operating Co. had requested and received permission to flare natural gas that comes up with the oil it pumps from the Eagle Ford Shale. Exco flared off the gas following its emergence from bankruptcy, claiming inability to afford the cost of pipeline transport of the gas. Although natural gas flaring has long been restricted in Texas, the Commission has granted exceptions with increasing frequency in the past years.

- October 24, 2019 – In a 2017 settlement with Exxon which was sealed but obtained by *Inside Climate News*, residents documented illnesses and property damage following the rupture of Exxon's Pegasus pipeline that sent heavy crude oil diluted with dangerous

[1976] David Templeton and Don Hopey, "Next Door Noise: Washington County Residents Say Their Neighbor Is Noisy, Disruptive and a Pollutor," *Pittsburgh Post-Gazette*, March 9, 2020, https://newsinteractive.post-gazette.com/smith-township-compressor-station-three-brothers/.
[1977] Office of the Inspector General, "Concerns Pertaining to Gas Transmission Lines at the Indian Point Nuclear Power Plant" (United States Nuclear Regulatory Commission, 2020), https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML20056F095.
[1978] "Lowey, Latimer Blast NRC for 'Faulty Analysis' That Led to Approval of Gas Line near Indian Point," *Mid Hudson News*, February 28, 2020, https://midhudsonnews.com/2020/02/27/lowey-latimer-blast-nrc-for-faulty-analysis-that-led-to-approval-of-gas-line-near-indian-point/.
[1979] Kiah Collier, "Pipeline Giant Sues Railroad Commission, Alleging Lax Oversight of Natural Gas Flaring," *The Texas Tribune*, December 3, 2019, https://www.texastribune.org/2019/12/03/railroad-commission-sued-lax-oversight-natural-gas-flaring/.

solvents spilling into a subdivision in Mayflower, Arkansas.[1980] Residents subsequently filed a class action lawsuit against Exxon alleging negligence in its maintenance of the 69-year-old pipeline. They faced "significant risks" after being exposed to a cocktail of chemicals including benzene, a known carcinogen; cyclohexane; naphthalene; and toluene, according to an environmental consultant hired by the plaintiffs' lawyers. The residents reportedly were awarded between $2,000 and $15,000. Exxon denied liability, claiming it "acted in conformity with generally recognized, state-of-the-art standards in the industry."

- October 10, 2019 – The Texas Railroad Commission, which oversees the state's oil and gas activity, rejected specific safety proposals drafted by its own staff for rural gathering lines and opted instead for vaguer requirements. This decision was praised by pipeline operators.[1981] Gathering lines are typically small-diameter, low-pressure pipelines carrying oil and gas from wells to processing sites, but recently industry has been building larger and higher-pressure pipelines that legally qualify as gathering lines. This new ruling allows gathering lines to escape regulations in remote, rural areas despite their size.

- June 4, 2019 – At least six pipeline explosions were caused by landslides, sinking and caving of land, and other types of land movement in the steeply sloped Appalachian mountains.[1982] Among them: TransCanada Corp's Leach Xpress natural gas pipeline exploded and demolished a house in Moundsville, West Virginia after five months in operation; a landslide caused a pipeline explosion near Aliquippa, Pa., burning down a house; and a boy and his grandfather were injured in an explosion in southeastern Ohio. An *E&E* investigation examined the gaps in comprehensive oversight: while PHMSA is responsible for the safety of construction and adherence to the agency's minimum standards, they are not involved in pipeline routes. That is handled by a different agency, FERC, which reviews how the path selection will affect the environment. The commission defers on safety issues to PHMSA. Thus, no one entity is in charge of ensuring that pipelines are built in safe places.

- May 7, 2019 – University at Albany researchers investigated health harms associated with chemical emissions from natural gas compressor stations in New York State. Between 2008 and 2014, 18 gas compressor stations (out of 74 compressors in the state) released a total of 36.99 million pounds of air pollutants, excluding methane and carbon dioxide. Thirty-nine of the chemicals released were human carcinogens. The study also included a greenhouse gas inventory, with data available for ten of the compressors.

[1980] David Hasemyer, "6 Years After Exxon's Oil Pipeline Burst in an Arkansas Town, a Final Accounting," *Inside Climate News*, October 24, 2019, https://insideclimatenews.org/news/24102019/exxon-oil-spill-neighborhood-mayflower-arkansas-sealed-depositions-illnesses-fines/.
[1981] Mike Soraghan, "Texas Commissioners Scale Back Gathering Line Proposal," *E&E News*, October 10, 2019, https://web.archive.org/web/20191010213035/https://www.eenews.net/stories/1061235103.
[1982] Mike Soraghan, "Landslides, Explosions Spark Fear in Pipeline Country," *E&E News*, June 4, 2019, https://web.archive.org/web/20190607095016/https://www.eenews.net/stories/1060472727.

Those facilities released 6.1 billion pounds of greenhouse gases release in a single year.[1983] (See also entry for October 12, 2017 below.)

- May 2, 2019 – Eight months after heavy rains and landslides led to the rupture and explosion of Energy Transfer's natural gas liquids Revolution Pipeline in Beaver County, Pennsylvania, destroying a house and knocking down power lines, PHMSA issued an advisory bulletin for operators of gas and hazardous liquid pipelines to "remind" them of the potential for damage from flooding, landslides, subsidence and other geologic hazards.[1984] The advisory bulletin reviewed specific guidance for monitoring, risk identification, and preventative and mitigative measures, as well as the many recent geological-related pipeline failures, particularly in the eastern portion of the United States. Unlike a regulation, a federal advisory is not enforceable but serves as a warning and a reminder of the regulations that are associated with pipeline safety. (See also entry for September 10, 2018 below.)

- March 4, 2019 – *E&E News* investigated accidents involving "gathering lines," which are small diameter pipelines that carry oil or gas from wellheads to processing facilities. Nationally, there are 450,000 miles of gathering lines. However, only high-pressure gathering lines in urban areas are regulated, and these represent only 18,000 miles of pipeline. The Pipeline and Hazardous Materials Safety Administration (PHMSA) has no rules for the rest. Nor do most states. Hence, it is not known how many fatalities have occurred due to explosions of gathering lines because no records are kept in rural areas. Rural gathering lines "don't have to be marked, built to standards or regularly inspected. Unlike for transmission lines, operators don't have to have emergency response plans for when they leak or explode."[1985]

- February 20, 2019 – During a polar vortex on January 30, 2019, a compressor station at an underground gas storage depot in Macomb County, Michigan was destroyed by an explosion after an equipment malfunction triggered emergency venting of gas. The extremely low temperatures prevented the methane plume from dispersing, and high winds pushed it along the ground until the gas encountered heat from another compressor station and exploded. The resulting gas shortage necessitated a statewide emergency call to residents and businesses to voluntarily turn down thermostats and reduce natural gas use. General Motors in Flint suspended operations for three days.[1986]

[1983] Pasquale N. Russo and David O. Carpenter, "Air Emissions from Natural Gas Facilities in New York State," *International Journal of Environmental Research and Public Health* 16, no. 9 (2019): 1591, https://doi.org/10.3390/ijerph16091591.
[1984] Pipeline Hazardous Materials Safety Administration, "Pipeline Safety: Potential for Damage to Pipeline Facilities Caused by Earth Movement and Other Geological Hazards," *Federal Register*, May 2, 2019, https://www.federalregister.gov/documents/2019/05/02/2019-08984/pipeline-safety-potential-for-damage-to-pipeline-facilities-caused-by-earth-movement-and-other.
[1985] Mike Lee and Mike Soraghan, "Deadly Pipelines, No Rules," *E&E News*, March 4, 2019, https://web.archive.org/web/20190304182624/https://www.eenews.net/stories/1060123021.
[1986] Beth LeBlanc, "Consumers CEO: Two Natural Gas Plants Still down after Jan. 30 Fire," *The Detroit News*, February 20, 2019, https://www.detroitnews.com/story/news/local/michigan/2019/02/20/consumers-energy-two-plants-still-down-after-fire-emergency-appeal/2928041002/.

- January 1, 2019 – As part of the planned Atlantic Bridge pipeline project, which will ferry fracked natural gas from New Jersey through New England and into Canada, Calgary-based Enbridge Inc. (formerly Spectra Energy) applied to site a 7,700-horsepower compressor station in Weymouth, Massachusetts, south of Boston. The Enbridge compressor station in Weymouth would maintain pipeline pressure needed to push the gas north to Maine and Canada. In 2016, the company offered the town $47 million to drop its opposition to the plan, which would place the compressor station in a port area immediately adjacent to densely populated neighborhood, the highly utilized Fore River lift bridge, a power plant, a sewage pumping station, and a gas metering station. Instead, residents and local political leaders rejected this offer and demanded a Health Impact Assessment (HIA). Ordered by Governor Charlie Baker in July 2017 and released in January 2019, this study received considerable criticism from the public health community due to its deviation from standard HIA methodologies. The HIA showed that the Fore River Basin already suffered from levels of benzene, formaldehyde, and other air toxics that exceeded state guidelines for these carcinogens while concluding that adding another source of these same pollutants would have negligible impact on residents' health.[1987, 1988] Shortly thereafter, the Massachusetts Department of Environmental Protection issued an air quality permit for the compressor station. This decision—and the HIA's conclusion on which it was based—was immediately contested by independent public health researchers. In February 2019, Greater Boston Physicians for Social Responsibility (GBPSR) issued their own report on the health risks of the Weymouth compressor that outlined their concerns about the safety and emergency response hazards associated with the proposed compressor and rejected the "no health impact" conclusion of the HIA. While the HIA acknowledged that the residents of the Fore River Basin already experienced excess rates of lung disease, heart disease, and cancer, the GBPSR report argued that disproportionately health-burdened people "require greater, not lesser, environmental safeguards."[1989, 1990] At this writing, the air quality permit, which was greenlighted by the HIA's findings, is under appeal before the Massachusetts Department of Environmental Protection.

- December 18, 2018 – "Given that many pipelines transport volatile, flammable, or toxic oil and liquids, and given the potential consequences of a successful physical or cyber-attack, pipeline systems are attractive targets for terrorists, hackers, foreign nations, criminal groups, and others with malicious intent," according to a report from the U.S. Government Accountability Office that urged the U.S. Department of Homeland

[1987] The Massachusetts Department of Environmental Protection, the Massachusetts Department of Public Health, & the Metropolitan Area Planning Council, "Health Impact Assessment of a Proposed Natural Gas Compressor Station in Weymouth, MA," January 1, 2019, https://www.mass.gov/files/documents/2019/02/14/Health-Impact-Assessment-Weymouth-Final-Report.pdf.
[1988] Jessica Trufant, "Regulators Issue Air Permit for Weymouth Compressor Station," *The Patriot Ledger, Quincy, MA*, January 11, 2019, https://www.patriotledger.com/news/20190111/regulators-issue-air-permit-for-weymouth-compressor-station.
[1989] Greater Boston Physicians for Social Responsibility, "Health Risks of A Proposed Compressor Station in Weymouth, Massachusetts," February 7, 2019, https://d279m997dpfwgl.cloudfront.net/wp/2019/02/GB-PSR-Report-on-Health-Risks-of-Proposed-Weymouth-Compressor-Station_Feb-7-2019.pdf.
[1990] Jessica Trufant, "Doctors' Group Challenges Report on Weymouth Compressor Station," *The Patriot Ledger, Quincy, MA*, February 7, 2019, https://www.patriotledger.com/news/20190207/doctors-group-challenges-report-on-weymouth-compressor-station.

Security's Transportation Security Administration (TSA) to address weaknesses in its management of pipeline security. TSA oversees the physical security and cybersecurity of the more than 2.7 million miles of gas, oil, and hazardous liquid pipelines in the United States.[1991]

- December 14, 2018 – The California Public Utilities Commission (CPUC) took action against Pacific Gas and Electric Company (PG&E) for what CPUC said are systemic violations of rules to prevent damage to natural gas pipelines during excavation activities. PG&E had been noncompliant with the law pertaining to the locating and marking of natural gas distribution pipelines, as well as related requirements to inform construction personnel and private persons on the location of PG&E's underground pipes and other natural gas infrastructure in a timely and accurate manner.[1992, 1993, 1994]

- December 10, 2018 – The Atlantic Coast Pipeline is a 600-mile project led by Dominion Energy that would extend from West Virginia to eastern North Carolina. Construction was halted when the U.S. Court of Appeals stayed a permit from the U.S. Fish and Wildlife Service that had authorized building the pipeline in critical habitat for four endangered species: the Indiana bat, the rusty-patched bumblebee, the clubshell mussel, and a shrimp-like crustacean called the Madison Cave isopod.[1995]

- November 15, 2018 – An *E&E News* analysis of interstate pipeline enforcement found that interstate pipelines have caught fire or exploded 137 times since 2010. In 90 percent of those disasters, no fines were levied by PHMSA (the federal agency that directly regulates 350,000 miles of pipelines, more than 400 natural gas storage facilities, and 26 liquefied natural gas facilities). PHMSA's reluctance to levy fines is a direct result of federal pipeline laws, which were largely drafted after 1994 when deregulation was a federal priority.[1996]

- November 1, 2018 – A Russian team used a cartographic model to assess the potential impact on health and environment of compressor station emissions during scheduled

[1991] U.S. Government Accountability Office, "Critical Infrastructure Protection: Actions Needed to Address Significant Weaknesses in TSA's Pipeline Security Program Management," December 18, 2018, https://www.gao.gov/products/gao-19-48.
[1992] California Public Utilities Commission (CPUC), "Order Instituting Investigation and Order to Show Cause," December 14, 2018, https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M246/K120/246120841.PDF.
[1993] California Public Utilities Commission (CPUC), "CPUC Opens Case Against PG&E for Potential Natural Gas Safety Violations," Press Release, December 14, 2018, http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M250/K897/250897740.PDF.
[1994] Richard Gonzales, "PG&E Falsified Gas Pipeline Safety Records, Regulators Say," *NPR*, December 14, 2018, sec. National, https://www.npr.org/2018/12/14/677003961/pg-e-falsified-gas-pipeline-safety-records-regulators-say.
[1995] John Murawski, "Atlantic Coast Pipeline: Construction Halts for Endangered Species," *The News & Observer*, December 10, 2018, https://www.newsobserver.com/news/business/article222856155.html.
[1996] Mike Soraghan, "No Penalties for 90% of Pipeline Blasts," *E&E News*, November 15, 2018, https://web.archive.org/web/20181115220003/https://www.eenews.net/stories/1060106253.

outages and repairs. They described a method of gas flow redistribution that would obviate the need for large-scale venting of methane into the atmosphere.[1997]

- October 11, 2018 – Overpressurizing a natural gas distribution system while replacing aging pipelines triggered 80 simultaneous natural gas explosions in Massachusetts' Merrimack Valley on September 13, 2018. One teenager was killed, 23 were injured, 130 buildings were destroyed or damaged, and thousands evacuated from communities in Lawrence, Andover, and North Andover. The explosions cost Columbia Gas more than $1 billion.[1998]

- September 10, 2018 – A landslide triggered by four days of intense rain caused a pipeline explosion that burned down a house in Beaver County, Pennsylvania and prompted evacuations. This pipeline, built by Energy Transfer Partners (which merged with Sunoco in 2017), was part of the Mariner 2 East Pipeline that is intended to carry the liquid hydrocarbon, ethane, to coastal ports where it will be exported for plastics manufacturing abroad. In western Pennsylvania, ethane co-occurs with methane in the shale bedrock and is released during fracking operations.[1999, 2000, 2001]

- August 10, 2018 – A joint investigation by the *Charleston Gazette-Mail* and *ProPublica* found that pipeline operators continue to break environmental rules, and state and federal agencies continue to clear roadblocks to allow these projects to move forward despite serious unanswered questions.[2002]

- July 25, 2018 – The Attorneys General of six states (Massachusetts, Rhode Island, New Jersey, Maryland, Illinois, Washington) and the District of Columbia submitted comments to the Federal Energy Regulatory Commission (FERC) on how the Commission should revise its approach to certifying new natural gas transportation facilities. They recommended that the Commission assess need on a comprehensive, regional basis; consider environmental harm, including climate impacts that consider the social costs of carbon; and more heavily weigh the harm of eminent domain. They urged

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[1997] Alexey Strizhenok and Denis Korelskiy, "Estimation and Reduction of Methane Emissions at the Scheduled and Repair Outages of Gas-Compressor Units," *Journal of Ecological Engineering* 20, no. 1 (January 1, 2019): 46–51, https://doi.org/10.12911/22998993/93943.
[1998] National Transportation Safety Board, "Pipeline Over-Pressure of a Columbia Gas of Massachusetts Low-Pressure Natural Gas Distribution System," Accident report (National Transportation Safety Board, October 11, 2018), https://permanent.fdlp.gov/gpo111468/PLD18MR003-preliminary-report.pdf.
[1999] Kris Mamula and Anya Litvak, "Officials Believe Landslide May Have Triggered Massive Gas Pipeline Explosion in Beaver County | Pittsburgh Post-Gazette," *Pittsburgh Post-Gazette*, September 10, 2018, https://www.post-gazette.com/local/west/2018/09/10/gas-explosion-in-center-township-Beaver-County/stories/201809100067.
[2000] Anya Litvak, "Pipeline Ruptures Bring New Scrutiny to Pennsylvania Geology," *AP News*, October 27, 2018, sec. Pennsylvania, https://apnews.com/article/2e0005ec7db342a290199a4d8464b5a0.
[2001] Anya Litvak, "Who Gets to Say Where It's Safe to Build a Pipeline? | Pittsburgh Post-Gazette," *Pittsburgh Post-Gazette*, September 14, 2018, https://www.post-gazette.com/business/powersource/2018/09/14/Who-gets-to-say-where-it-s-safe-to-build-a-pipeline-natural-gas-beaver-county-explosion-DEP-Pennsylvania/stories/201809140058.
[2002] Kate Mishkin and Ken Ward Jr., "What Happens When a Pipeline Runs Afoul of Government Rules? Authorities Change the Rules.," *ProPublica*, August 10, 2018, https://www.propublica.org/article/west-virginia-halted-mountain-valley-pipeline?token=SstV5uby4K1aF_9o7uU0NxUx4Lmau-1g.

better incorporation of state and local land use policies. And they recommended that the Commission no longer issue partial notices to proceed with construction when rehearing requests are pending.[2003]

- May 24, 2018 – The Office of the Inspector General at the Department of Energy audited FERC's Natural Gas Certification Process. It found that FERC lacked a consistent process for tracking public comments on proposed pipeline projects, suggesting that all comments might not be reviewed. "In the absence of a consistent methodology, we did not verify to what degree comments received by FERC were considered, aggregated, and reflected in the environmental documents or final orders for the certificate applications during our review," the report concluded. "The lack of a consistent methodology could increase the risk that FERC may not address significant and impactful public comments in the environmental document or final order."[2004, 2005]

- May 16, 2018 – A team of researchers in Alberta, Canada investigated how noise from natural gas compressor stations and oil wells affected the behavior and communication of Savannah sparrows (*Passerculus sandwichensis*). The results showed that alarm responses and feeding visits were impaired by noise-producing infrastructure. Savannah sparrows were less vigilant when provisioning nestlings and distracted from their reproductive tasks when in the vicinity of compressor stations. "Our observation that Savannah sparrows are less responsive to anti-predator signals in the vicinity of natural gas compressor stations is of conservation concern and adds to a growing body of evidence that noisy anthropogenic structures have the potential to negatively affect birds by interfering with acoustic communication."[2006] Previous research in the same region found that the Savannah sparrow altered its song structure and song features when exposed to noise from oil and gas infrastructure, including compressor stations, and that these noise-altered songs were less effective at provoking responses from other birds.[2007, 2008]Similarly, researcher working in the San Juan Basin of New Mexico found that chronic noise from drilling and fracking operations, including compressor stations,

[2003] Federal Energy Regulatory Commission, "Comments of the Attorneys General of Massachusetts, Illinois, Maryland, New Jersey, Rhode Island, Washington, and the District of Columbia," Docket, July 25, 2018, https://www.mass.gov/files/documents/2018/07/26/Multistate%20Comments-FERC%201999%20PL%20Policy%20Review.pdf.
[2004] Phil McKenna, "Public Comments on Pipeline Plans May Be Slipping Through Cracks at FERC, Audit Says," *Inside Climate News*, May 31, 2018, https://insideclimatenews.org/news/31052018/public-comments-oil-gas-pipelines-ferc-review-energy-department-inspector-general-audit/.
[2005] Office of the Inspector General at the Department of Energy, "The Federal Energy Regulatory Commission's Natural Gas Certification Process," Audit Report, May 24, 2018, https://www.energy.gov/ig/downloads/audit-report-doe-oig-18-33.
[2006] Bridget Antze and Nicola Koper, "Noisy Anthropogenic Infrastructure Interferes with Alarm Responses in Savannah Sparrows (*Passerculus Sandwichensis*)," *Royal Society Open Science* 5, no. 5 (2018): 172168, https://doi.org/10.1098/rsos.172168.
[2007] Miyako H. Warrington et al., "Noise from Four Types of Extractive Energy Infrastructure Affects Song Features of Savannah Sparrows," *The Condor* 120, no. 1 (2017): 1–15, https://doi.org/10.1650/CONDOR-17-69.1.
[2008] Claire M. Curry et al., "Noise Source and Individual Physiology Mediate Effectiveness of Bird Songs Adjusted to Anthropogenic Noise," *Scientific Reports* 8, no. 1 (2018): 3942, https://doi.org/10.1038/s41598-018-22253-5.

affected levels of stress hormones in songbirds and masked critical acoustic cues in ways that decreased the birds' ability to survive and reproduce.[2009, 2010]

- April 26, 2018 – Studies that investigate the health impacts of drilling and fracking activities typically incorporate the distance between participants' home addresses and well pads and do not consider potential exposures to emissions from other ancillary pieces of infrastructure. A study led by Johns Hopkins University researchers working in Pennsylvania attempted to develop exposure metrics for air emissions from compressor stations, flare stacks, and impoundments. The research team identified 457 compressor stations in Pennsylvania and 1419 compressor station engines. Data on compressor stations engines were not available electronically, and only 361 stations could be confirmed as operational. The team found that compressor engines, impoundments, and flaring events are all potential sources of emissions related to drilling and fracking that have not previously been accounted for in epidemiological studies "in part because data are not readily available. The value of including these additional sources of information on [fracking], particularly in health studies, remains unknown."[2011]

- April 26, 2018 – Pipelines are inspected and cleaned through a process called pigging, in which devices are placed inside, and travel through, the pipe. Pigs can be used to force water or air through a pipeline, check for obstructions, detect leaks, scrape debris from the pipe wall, prevent corrosion, or apply coatings. Pigging is necessarily accompanied by venting of hydrocarbon gases into the air, including methane. A federal settlement acknowledged that the use of the maintenance pigging technique is a major source of harmful emissions in pipeline systems carrying fracked gas extracted from shale that also contains other hydrocarbons, such as natural gas liquids. "The settlement between the U.S. Department of Justice, Environmental Protection Agency and Pennsylvania Department of Environmental Protection and two MarkWest subsidiaries … alleges the company failed to apply for or comply with air pollution permits. As a result, the company unlawfully vented hundreds of tons of natural gas and volatile organic compounds."[2012]

- October 12, 2017 – Researchers at University of Albany's Institute for Health and the Environment prepared a 300-page technical report on the health effects of the emissions from 18 natural gas compressor stations in New York State. The team found that, collectively, these sites released 40 million pounds of 70 different contaminants over a seven-year period, making natural gas compressor stations the seventh largest point

[2009] Nathan J. Kleist et al., "Chronic Anthropogenic Noise Disrupts Glucocorticoid Signaling and Has Multiple Effects on Fitness in an Avian Community," *Proceedings of the National Academy of Sciences* 115, no. 4 (2018): E648–57, https://doi.org/10.1073/pnas.1709200115.
[2010] University of Colorado at Boulder, "Noise from Oil and Gas Operations Stresses Birds, Hinders Reproduction," News Release (AAAS EurekAlert, January 8, 2018), https://www.eurekalert.org/news-releases/896481.
[2011] Kirsten Koehler et al., "Exposure Assessment Using Secondary Data Sources in Unconventional Natural Gas Development and Health Studies," *Environmental Science & Technology* 52, no. 10 (2018): 6061–69, https://doi.org/10.1021/acs.est.8b00507.
[2012] Brittany Patterson, "MarkWest Agrees to Pay Millions in Federal Settlement Over 'Pig' Emissions," *West Virginia Public Broadcasting*, April 26, 2018, sec. WVPB News, https://www.wvpublic.org/news/2018-04-26/markwest-agrees-to-pay-millions-in-federal-settlement-over-pig-emissions.

source of air pollution in the state. By volume, the largest emissions were nitrogen oxides, carbon monoxide, volatile organic compounds (VOCs), formaldehyde, and particulate matter. Exposure to these chemicals is linked to cancer, as well as cardiovascular, neurological, and developmental disorders. The authors noted, "The potential health impacts of the large volumes of pollutants generated by natural gas compressor stations have not been addressed, let alone answered, by those arguing for their construction and expansion."[2013]

- October 11, 2017 – A study of airborne methane emissions from assorted components of natural gas infrastructure in California, including compressor stations and storage facilities, confirmed earlier studies in finding widely variable leakages. The results suggested that a significant fraction of the methane emitted from storage facilities may, in fact, be escaping from their associated compressor stations.[2014]

- July 17, 2017 – A comprehensive investigation of the pipeline approval process by the Center for Public Integrity, *StateImpact Pennsylvania,* and National Public Radio found that FERC, which is charged with ensuring the public's interest, routinely assesses need based on company filings and functions as an agency captured by industry interests, concluding, "at every turn, the agency's process favors the pipeline companies." The result, according to this analysis of more than 500 pipeline cases, is that the financial interests of the gas industry, and not market demand or public necessity, is driving the ongoing pipeline build-out. In some cases, utility companies have complex financial ties to the pipeline companies that service them.[2015] Continuing this investigation, *Inside Climate News* then reviewed several large, new pipeline proposals in the Marcellus and Utica Shale regions, focusing on joint ventures and interlocking financial relationships between customers (state-regulated utilities) and suppliers (pipeline companies). Affiliate agreements that allow parent companies of utilities to seek federal certificates for interstate pipelines—which typically allow a 14 percent return on equity—contribute to the ongoing frenzy of pipeline construction even when natural gas demand is flat. Existing pipelines, the investigation noted, run at only slightly more than half capacity.[2016]

- July 12, 2017 – A Canadian study found that oil and gas infrastructure, including compressor stations, contributes to habit fragmentation and increases parasitism by

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[2013] D. O. Carpenter and P. N. Russo, "Health Effects Associated with Stack Chemical Emissions from NYS Natural Gas Compressor Stations: 2008-2014," Technical Report (Southwest Pennsylvania Environmental Health Project, n.d.), http://www.environmentalhealthproject-ny.org/uploads/3/8/5/9/38599771/ny_compressor_station_report_power_point_10.11.2017.pdf.

[2014] Shobhit Mehrotra et al., "Airborne Methane Emission Measurements for Selected Oil and Gas Facilities Across California," *Environmental Science & Technology* 51, no. 21 (2017): 12981–87, https://doi.org/10.1021/acs.est.7b03254.

[2015] Kristen Lombardi and Jamie Smith Hopkins, "Natural Gas Building Boom Fuels Climate Worries, Enrages Landowners," *NPR*, July 17, 2017, https://www.npr.org/2017/07/17/536708576/natural-gas-building-boom-fuels-climate-worries-enrages-landowners.

[2016] Phil McKenna, "Pipeline Payday: How Builders Win Big, Whether More Gas Is Needed or Not," *Inside Climate News*, August 3, 2017, https://insideclimatenews.org/news/03082017/natural-gas-pipeline-boom-corporate-profit-bubble-limited-demand-climate-emissions/.

cowbirds on Savannah sparrow nests in the Northern Great Plains. Populations of North American grassland songbirds, including the Savannah sparrow, are declining precipitously, mostly due to habitat loss and degradation. These results suggest that "brood parasitism associated with oil and natural gas infrastructure may result in additional pressures that reduce the productivity of this declining grassland songbird."[2017]

- May 16, 2017 – An analysis of records from state agencies revealed that low-pressure flow lines at oil and gas well sites are responsible for more than 7,000 spills, leaks, and accidents since 2009. Flow lines carry oil, gas, or wastewater from scattered pieces of equipment within a production site. Other than in New Mexico, operators are not required to report gas leaks from flow lines. A fatal explosion in April 2017 in a Firestone, Colorado home built on top of an oil field was triggered when an abandoned flow line seeped gas into a basement where it ignited. Two people were killed and one person was badly injured. Soon after, Colorado Governor John Hickenlooper ordered a statewide review of all oil and gas lines located near occupied buildings. Preliminary data showed that 16,000 wells across Colorado have flow lines that lie within 1,000 feet of homes. Corrosion is a leading cause of flow line failures.[2018, 2019]

- February 15, 2017 – A team of researchers from University of Texas investigated emissions from natural gas compressor stations throughout Pennsylvania and New York. They found that compressors emitted highly variable plumes of methane that spread downwind and were measurable a full mile away at levels that could expose nearby residents, especially during temperature inversions. The researchers concluded, "Our data indicate that compressor stations are likely sources of methane emissions and presumably co-emitted air contaminants, and can sporadically/episodically emit methane at relatively high levels…if such facilities are to be permitted to release specified amounts of contaminants, those amounts should be actively measured and verified. Without measurement there can be no assurance that permit conditions are being met."[2020]

- November 30, 2016 – A CityLab investigation used data from the Pipeline and Hazardous Materials Safety Administration to map all significant U.S. pipeline accidents between 1986 and 2016 and concluded, "wherever pipelines are extended, deadly accidents will follow." Pipeline accidents over the past 30 years have resulted in 548 deaths, more than 2,500 injuries, and over $8.5 billion in damages. Accidents are particularly common in Texas and Louisiana.[2021]

[2017] Jacy Bernath-Plaisted, Heather Nenninger, and Nicola Koper, "Conventional Oil and Natural Gas Infrastructure Increases Brown-Headed Cowbird (*Molothrus Ater*) Relative Abundance and Parasitism in Mixed-Grass Prairie," *Royal Society Open Science* 4, no. 7 (2017): 170036, https://doi.org/10.1098/rsos.170036.
[2018] Mike Soraghan, "Flow Lines Cited in More than 7K Spills," *E&E News*, May 16, 2017, https://web.archive.org/web/20170516233919/https://www.eenews.net/stories/1060054568.
[2019] Mike Lee, "Fatal Explosion Threatens More Upheaval over Drilling in Colo," *E&E News*, June 12, 2017, https://web.archive.org/web/20180828194551/https://www.eenews.net/stories/1060055846.
[2020] Bryce F. Payne et al., "Characterization of Methane Plumes Downwind of Natural Gas Compressor Stations in Pennsylvania and New York," *Science of The Total Environment* 580 (2017): 1214–21, https://doi.org/10.1016/j.scitotenv.2016.12.082.
[2021] George Joseph, "30 Years of Oil and Gas Pipeline Spills, Mapped - Bloomberg," *CityLab*, November 30, 2017, https://www.bloomberg.com/news/articles/2016-11-30/30-years-of-oil-and-gas-pipeline-spills-mapped.

- July 5, 2016 – The National Energy Board, Canada's pipeline watchdog, gave two of Canada's largest pipeline companies six months to fix severe deficiencies in pipelines, ultimately issuing an emergency safety order in February 2016. Newly released federal documents showed that Texas-based Kinder Morgan and Alberta-based Enbridge were both looking into the use of defective parts purchased from Thailand-based Canadoil Asia that recently went bankrupt. U.S. regulators warned of these deficiencies eight years prior. At least one Canadian pipeline with defective materials exploded during that period.[2022]

- June 10, 2016 – EPA Region 2 submitted comments to FERC on Docket Nos. PFI6-3, Eastern System Upgrade Project, which includes new natural gas compressor stations in Hancock and Highland, New York. The EPA submission suggested an analysis of whether this project was needed; clarification of what is meant by a loop system; evaluation of alternatives; a comprehensive analysis of cumulative, indirect, and secondary impacts; information on greenhouse gas emissions and climate change impacts; a Health Impact Assessment; the inclusion of all pollution prevention practices; and a consideration of environmental justice concerns.[2023] The company agreed to provide funding toward a health study but wished to retain the ability to determine the study parameters.[2024] Skeptical of the health study's funding and parameters, residents and potentially impacted towns objected to the company's dismissal of the towns' laws prohibiting the construction and operation of heavy industrial use facilities. The Deputy Supervisor of one of the affected towns "said he was encouraged by the federal Environmental Protection Agency's comments on the project's preliminary federal application. He said the EPA concerns were 'the same as ours.'"[2025]

- April 27, 2016 – In its report on two natural gas pipeline expansion projects in Appalachia, the Institute for Energy Economics and Financial Analysis demonstrated that the Atlantic Coast and Mountain Valley pipelines are "emblematic of the risks that such expansion creates for ratepayers, investors and landowners." The report concluded that pipelines out of the Marcellus and Utica region are being overbuilt, putting ratepayers at risk of paying for excess capacity, landowners at risk of losing their property to unnecessary projects, and investors at risk of loss. The report stated that FERC facilitates this building of excess pipeline capacity and its approach for assessing need is insufficient.[2026]

[2022] Mike De Souza, "How Canada's Pipeline Watchdog Secretly Discusses 'Ticking Time Bombs' with Industry," *Canada's National Observer*, July 5, 2016, sec. News, https://www.nationalobserver.com/2016/07/05/news/how-canada%E2%80%99s-pipeline-watchdog-secretly-discusses-ticking-time-bombs-industry.
[2023] US EPA Region 2, "Docket Nos. PFI6-3, Eastern System Upgrade Project," June 10, 2016, https://elibrary.ferc.gov/idmws/file_list.asp?document_id=14468753.
[2024] F. Mayer, "Millennium to Pay for Health Study," *The River Reporter*, April 27, 2016, https://riverreporter.com/stories/millennium-to-pay-for-health-study,1279.
[2025] David Hulse, "Highland Concerned about Study Underfunding," *The River Reporter*, June 22, 2016, https://riverreporter.com/stories/highland-concerned-about-study-underfunding,945.
[2026] Cathy Kunkel and Tom Sanzillo, "Risks Associated With Natural Gas Pipeline Expansion in Appalachia: Proposed Atlantic Coast and Mountain Valley Pipelines Need Greater Scrutiny" (Institute for Energy Economics

- April 22, 2016 – The federal Agency for Toxic Substances and Disease Registry (ATSDR) released a report on air quality near a natural gas compressor station in Brooklyn Township, Susquehanna County, Pennsylvania, finding levels of fine particulate matter (PM2.5) at levels that can damage human health in those with long-term exposure. Evaluating data from an 18-day EPA field air monitoring event, the report found that the average ambient 24-hour PM2.5 concentration observed at one residence (19 μg/m3) was higher than the nearest regional National Ambient Air Quality Standards (NAAQS) monitoring station (12.3 μg/m3) in Scranton, PA, over the same period. ATSDR concluded that there was evidence that long-term exposure to PM2.5 at the levels found can cause an increase in mortality, respiratory problems, hospitalizations, preterm births, and low birth weight. The agency said that in the short term, exposure could be harmful to sensitive populations, such as those with respiratory problems or heart disease. The agency recommended that sensitive individuals monitor air quality and limit activity accordingly, and that the PA DEP work to reduce other sources of PM and its precursors.[2027]

- April 3, 2016 – The Southwest Pennsylvania Environmental Health Project issued a *Technical Report* in response to the January 29, 2016 federal ATSDR report on the Brigich compressor station in Chartiers Township, Washington County, Pennsylvania. ATSDR detected chemicals that had been reported at gas sites previously, and this confirmation of their presence provided "an important acknowledgement that neighbors of such facilities are being exposed (often at very close range) to chemicals that bring with them the possibility of short- and long-term health effects." The report stated that, in conjunction with the monitoring work of the EPA, ATSDR "provided a solid set of data." However, due to the limitations of the methodologies available to them, the authors were "concerned that there was, in the end, an underestimate of risk to community members."[2028]

- April 1, 2016 – Kinder Morgan, the largest energy infrastructure company in North America, suspended construction of a $1 billion pipeline project that would have carried gasoline and diesel fuel across the southeastern United States. Construction was suspended after landowners protested the seizure of their property, a Georgia Superior Court judge upheld a decision denying a certificate that would have allowed the company

and Financial Analysis, 2016), http://ieefa.org/wp-content/uploads/2016/04/Risks-Associated-With-Natural-Gas-Pipeline-Expansion-in-Appalachia-_April-2016.pdf.

[2027] U.S. Department of Health and Human Services, "Brooklyn Township PM2.5 Brooklyn Township, Susquehanna County, Pennsylvania," Health Consultation (Agency for Toxic Substances and Disease Registry, Division of Community Health Investigations, April 22, 2016), https://www.atsdr.cdc.gov/HAC/pha/BrooklynTownship/BrooklynTwnsp_pm2-5_HC_Final_04-22-2016_508.pdf.

[2028] Southwest Pennsylvania Environmental Health Project, "ATSDR Releases Investigation of Pennsylvania Compressor Station: Response to Governmental Action and Publication I," April 3, 2016, https://www.catskillcitizens.org/files/learnmore/brigichtechnicalreportfinal_1_.pdf.

to use eminent domain, and the state legislature passed legislation to block the property seizure.[2029]

- March 26, 2016 – According to a Boston University-led study, fugitive emissions from urban natural gas pipeline systems were the largest anthropogenic source of the greenhouse gas methane in the United States and contribute to the risk of explosions in urban environments, with 15 percent of leaks qualifying as potentially explosive.[2030] "All leaks must be addressed, as even small leaks cannot be disregarded as 'safely leaking,'" concluded the report authors. In an interview with *Inside Climate News*, the lead author said that in addition to weighing the safety risks from gas leaks, regulators and utility companies must also consider the climate impact of leaks when determining priorities for repairing and replacing pipes.[2031]

- March 7, 2016 – A lawsuit filed against FERC in U.S. District Court in Washington, D.C challenged the agency's relationship with industry, reported *Penn Live*: "The suit accuses the commission of regulatory capture, a situation in which corporations control regulators." FERC receives all of its funding from the energy companies that it regulates and had never rejected a pipeline plan, which, according to the complainant, demonstrates "clear bias and corruption."[2032]

- February 26, 2016 – Congressman Chris Gibson (NY-19), in response to citizen concerns, sent a letter to FERC regarding the proposed 41,000-horsepower compressor station in southern Rensselaer County, New York, part of the Northeast Energy Direct (NED) pipeline project. He discussed the inadequacy of federal exposure standards with regard to exposures at compressor sites and lack of medical expertise in these decisions. He requested public health expertise on all Environmental Assessment and Environmental Impact Statement teams, an independent panel to review the federal exposure standards around compressor stations, and "a transparent and effective review process."[2033] His call was supported by other elected officials, as well as public health researcher David O. Carpenter, MD, who has studied compressor station pollutants.[2034]

[2029] Phil McKenna, "Property Rights Outcry Stops Billion-Dollar Pipeline Project in Georgia," *Inside Climate News*, April 1, 2016, https://insideclimatenews.org/news/01042016/palmetto-pipeline-kinder-morgan-georgia-eminent-domain-oil-gas-republicans/.
[2030] Margaret F. Hendrick et al., "Fugitive Methane Emissions from Leak-Prone Natural Gas Distribution Infrastructure in Urban Environments," *Environmental Pollution* 213 (2016): 710–16, https://doi.org/10.1016/j.envpol.2016.01.094.
[2031] Phil McKenna, "Methane Hazard Lurks in Boston's Aging, Leaking Gas Pipes, Study Says," *Inside Climate News*, March 31, 2016, https://insideclimatenews.org/news/31032016/boston-natural-gas-pipelines-leaking-methane-climate-change-explosion/.
[2032] Candy Woodall, "Federal Agency Funded by Energy Industry Has Never Rejected a Pipeline Plan," *PennLive Patriot News*, March 7, 2016, sec. Pennsylvania Real-Time News, https://www.pennlive.com/news/2016/03/pipeline_fights_raise_big_ques.html.
[2033] Chris Gibson, "Compressor Station Needs Review," *Sullivan County Democrat*, February 26, 2016, https://www.scdemocratonline.com/stories/compressor-station-needs-review,47706?
[2034] Brian Nearing, "Gibson: Federal Natural Gas Air Pollution Safety Standards May Be Obsolete," *Times Union*, March 31, 2016, sec. Business, https://www.timesunion.com/business/article/Gibson-Federal-natural-gas-air-pollution-safety-7221271.php.

- January 29, 2016 – ATSDR, in collaboration with the EPA Region 3 Air Protection Division, conducted an exposure investigation to evaluate exposures of residents living near the Brigich natural gas compressor station in Chartiers Township, Washington County, Pennsylvania. ATSDR concluded that, although exposure to the levels of chemicals detected in the ambient air was not expected to harm the health of the general population, "some sensitive subpopulations (e.g., asthmatics, elderly) may experience harmful effects from exposures to hydrogen sulfide and PM 2.5 [and] [s]ome individuals may also be sensitive to aldehyde exposures, including glutaraldehyde." According to ATSDR, one of the study's limitations was that the sampling "may not have adequately captured uncommon but significant incidents when peak emissions (e.g. unscheduled facility incidents, blowdowns or flaring events) coincide with unfavorable meteorological conditions (e.g. air inversion)." ATSDR recommendations included reducing exposures to the chemicals of concern to protect sensitive populations, continued collection of emissions data for long-term and peak exposures, and air modeling to better understand ambient air quality.[2035]

- December 8, 2015 – The Niagara County Legislature, following the recommendations of the Medical Society of the State of New York, called for a Health Impact Assessment (HIA) on natural gas infrastructure, including compressor stations, and co-hosted a conference in Albany on the Medical Society's health findings. A compressor station with twin compressors, part of the "2016 Northern Access Plan" to transfer gas from Pennsylvania to Canada, is proposed for the county.[2036]

- November 9, 2015 – Following the 2010 heavy oil spill in Michigan's Kalamazoo River, Congress ordered an audit that spotlighted the industry's poor record of spotting leaks. *Politico* reported on the 2015 regulatory structure ultimately unveiled in response, determining the proposal "fails to patch that hole in the nation's pipeline safety net." "While the agency's proposed rule expands the number of pipelines that must have a leak-detection system in place, it sets no basic standards for how well that technology should work. Instead, safety advocates say, it lets pipeline operators decide for themselves whether they are adequately prepared."[2037]

- October 16, 2015 – The EPA urged FERC to consider "whether the Northeast Energy Direct pipeline could be combined with other projects, rather than constructing a new system that would have a host of environmental impacts," reported Oneonta, New York's *Daily Star*. The EPA also advised "that the gas demand addressed by NED's application

[2035] U.S. Department of Health and Human Services, "Exposure Investigation, Natural Gas Ambient Air Quality Monitoring Initiative Brigich Compressor Station, Chartiers Township, Washington County, Pennsylvania," Health Consultation (Agency for Toxic Substances and Disease Registry, Division of Community Health Investigations, January 29, 2016), http://www.atsdr.cdc.gov/HAC/pha/Brigich_Compressor_Station/Brigich_Compressor_Station_EI_HC_01-29-2016_508.pdf.
[2036] Staff Reports, "County Lawmakers Call for Study on Compressor Health Risks," *Lockport Union-Sun & Journal*, December 8, 2015, https://www.lockportjournal.com/news/local_news/county-lawmakers-call-for-study-on-compressor-health-risks/article_932989cd-058a-594f-9ef2-e52827db85a6.html.
[2037] Elana Schor and Andrew Restuccia, "The Hole in Obama's Pipeline Safety Plan," *Politico*, November 9, 2015, https://www.politico.com/story/2015/11/obama-pipeline-safety-plan-oil-215617.

could be met by renewable forms of energy such as solar and wind power…"[2038] (Note: Kinder Morgan withdrew its NED pipeline application in April 2016.)

- September 17, 2015 – At a shale gas conference, industry representatives espoused the construction of new pipelines as necessary to re-invigorate the gas industry in the Marcellus. Speakers noted that FERC approval can be expected to now take longer, by about six months, blaming environmental groups for the delays.[2039]

- September 9, 2015 – New pipelines are failing at a rate on par with gas transmission lines installed before the 1940s, according to an analysis of federal data by the Pipeline Safety Trust, reported by *S&P Global Market Intelligence*. "The gas transmission lines installed in the 2010s had an annual average incident rate of 6.64 per 10,000 miles over the time frame considered, even exceeding that of the pre-1940s pipes. Those installed prior to 1940 or at unknown dates had an incident rate of 6.08 per 10,000 miles." The director of the National Transportation Safety Board's Office of Railroad, Pipeline and Hazardous Materials Investigations "agreed that the rapid construction of pipelines in the U.S. is likely a contributing factor."[2040]

- August 18, 2015 – Houston Advanced Research Center (HARC) scientists addressed "the commonly acknowledged sources of uncertainty which are the lack of sustained monitoring of ambient concentrations of pollutants associated with gas mining, poor quantification of their emissions, and inability to correlate health symptoms with specific emission events." They concluded that "more contemporary monitoring and data analysis techniques should take the place of older methods to better protect the health of nearby residents and maintain the integrity of the surrounding environment." "Real-time mobile monitoring, microscale modeling and source attribution, and real-time broadcasting of air quality and human health data over the World Wide Web" have been demonstrated, they wrote, by past, current, and planned future monitoring studies in the Barnett and Eagle Ford shale regions.[2041] Founded as a technology incubator in 1982 by Houston oilman George P. Mitchell, HARC later re-aligned to focus on sustainable development.

- August 14, 2015 – HARC scientists found that port operations involving petrochemicals may significantly increase emissions of air toxics, including peaks of carcinogenic benzene of up to 37 ppb. The scientists matched the benzene spikes with pipeline systems. The spikes were at levels much higher than those reported in the EPA's 2011 National Emissions Inventory. The authors recommended the use of updated methods for

[2038] Joe Mahoney, "EPA: Can Local Pipeline Plans Merge?," *The Daily Star*, October 16, 2015, https://www.thedailystar.com/news/local_news/epa-can-local-pipeline-plans-merge/article_f2836510-a96b-5c2d-9892-755b94b1f640.html.
[2039] Dan Packel, "Energy Honchos Lament FERC Pipeline Approval Delays - Law360," *Law 360*, September 17, 2015, https://www.law360.com/articles/697120/energy-honchos-lament-ferc-pipeline-approval-delays.
[2040] Sarah Smith, "SNL: As US Rushes to Build Gas Lines, Failure Rate of New Pipes Has Spiked," *S&P Global*, September 9, 2015, https://www.snl.com/interactiveX/article.aspx?CDID=A-33791090-11060&ID=33791090&Printable=1.
[2041] Eduardo P. Olaguer et al., "Updated Methods for Assessing the Impacts of Nearby Gas Drilling and Production on Neighborhood Air Quality and Human Health," *Journal of the Air & Waste Management Association* 66, no. 2 (2016): 173–83, https://doi.org/10.1080/10962247.2015.1083914.

ambient monitoring.[2042] Lead scientist Jay Olaguer said in a related interview that "government regulators should wake up to the reality of the situation, that their methods of tracking air pollution need to be updated so that the samples are taken in real time and can catch it when toxic vapors of this magnitude are released."[2043]

- July 15, 2015 – Rensselaer County lawmakers passed a resolution asking the state of New York to freeze the approval process for the Northeast Energy Direct pipeline—which would carry fracked gas from Pennsylvania to Boston—until it conducts a comprehensive health impact assessment for natural gas pipelines.[2044]

- July 8, 2015 – Researchers from West Virginia University completed leak and loss audits for methane emissions at three natural gas compressor stations and two natural gas storage facilities, with a "leak" defined as an unintended release of natural gas due to malfunction of a component, and a "loss" defined as an intended release of natural gas. In terms of frequency, most emissions were leaks, but on a mass basis, losses were the dominant source of methane emissions (88 percent). The top loss emitters were engine exhausts (accounting for nearly half), packing vents, and slop tanks. Emissions from compressor blowdowns were not included.[2045] A related study by a University of Houston team found that emission rates from compressor stations in Texas' Barnett Shale were far higher than from well pads.[2046, 2047]

- July 7, 2015 – Seeking a method to bridge the gap between bottom-up and top-down methods of measuring methane emissions, Purdue University, University of Houston, the National Oceanic and Atmospheric Administration (NOAA), Environmental Defense Fund, and independent researchers surveyed eight high-emitting point sources in the Barnett Shale using an aircraft-based "mass balance" approach. Results from four gas processing plants and one compressor station highlighted the importance of addressing methane "super-emitters" and confirmed that self-reports from the Greenhouse Gas Reporting Program underestimated actual emission rates by a factor of 3.8 or higher, due to "underestimated facility emissions, temporal variability of emissions, and the exclusion of nonreporting facility emissions."[2048]

[2042] Eduardo P. Olaguer et al., "Source Attribution and Quantification of Benzene Event Emissions in a Houston Ship Channel Community Based on Real-Time Mobile Monitoring of Ambient Air," *Journal of the Air & Waste Management Association* 66, no. 2 (2016): 164–72, https://doi.org/10.1080/10962247.2015.1081652.
[2043] Dianna Wray, "Scientists Discover Pipelines Belching Benzene in East Houston," *Houston Press*, February 23, 2016, https://www.houstonpress.com/news/scientists-discover-pipelines-belching-benzene-in-east-houston-8181569.
[2044] Brian Nearing, "County: Put Study before Any Permit," *Times Union*, July 16, 2015, sec. News, https://www.timesunion.com/news/article/County-Put-study-before-any-permit-6387404.php.
[2045] Derek R. Johnson, April N. Covington, and Nigel N. Clark, "Methane Emissions from Leak and Loss Audits of Natural Gas Compressor Stations and Storage Facilities," *Environmental Science & Technology* 49, no. 13 (2015): 8132–38, https://doi.org/10.1021/es506163m.
[2046] Xin Lan et al., "Characterizing Fugitive Methane Emissions in the Barnett Shale Area Using a Mobile Laboratory," *Environmental Science & Technology* 49, no. 13 (2015): 8139–46, https://doi.org/10.1021/es5063055.
[2047] Lisa Song and Zahra Hirji, "Methane Emissions in Texas Fracking Region 50% Higher Than EPA Estimates," *Inside Climate News*, July 8, 2015, https://insideclimatenews.org/news/08072015/methane-emissions-texas-fracking-region-50-higher-epa-estimates-oil-gas-drilling-barnett-shale-environmental-defense-fund/.
[2048] Tegan N. Lavoie et al., "Aircraft-Based Measurements of Point Source Methane Emissions in the Barnett Shale Basin," *Environmental Science & Technology* 49, no. 13 (2015): 7904–13, https://doi.org/10.1021/acs.est.5b00410.

- July 7, 2015 – Using relatively easy-to-acquire and inexpensive stable isotopic and alkane ratio tracers, researchers are now able to distinguish methane arising from natural gas production and transport from agricultural and urban methane sources, and, in addition, to distinguish between methane released from shale gas as opposed to conventional wells. Initial research from the University of Cincinnati, University of California at Irvine, and the Environmental Defense Fund found that methane in the Barnett Shale hydraulic fracturing region near Fort Worth, Texas, represents a complex mixture of these sources. This new approach, used for ground-level measurements, can complement and extend top-down approaches, allowing for more accurate inventories of thermogenic and biogenic sources of methane emissions.[2049]

- July 1, 2015 – In New York State, Schoharie County supervisors and medical professionals demanded comprehensive health impact assessments as a precondition for permitting natural gas pipelines and compressor stations.[2050]

- June 12, 2015 – The Agency for Toxic Substances and Disease Registry investigated the health effects of ruptured gas pipelines in an analysis of data in a database on acute petroleum-related releases to which seven states contribute (Louisiana, New York, North Carolina, Oregon, Tennessee, Utah, and Wisconsin). From 2010 to 2012, there were 1,369 such incidents, which resulted in 259 injuries. More than three-quarters of these incidents were related to natural gas distribution. Equipment failure accounted for half of all incidents; human error accounted for 40 percent. The report noted the "continuing occurrence" of petroleum release incidents—including from natural gas pipeline ruptures—which have "the potential to cause mass casualties and environmental contamination."[2051]

- June 9, 2015 – The American Medical Association (AMA) adopted a resolution, "Protecting Public Health from Natural Gas Infrastructure," that was based on a resolution adopted by the Medical Society of the State of New York. (See below.) The resolution states, "Our AMA recognizes the potential impact on human health associated with natural gas infrastructure and supports legislation that would require a comprehensive Health Impact Assessment regarding the health risks that may be associated with natural gas pipelines."[2052]

- May 2, 2015 – The Medical Society of the State of New York adopted a resolution, "Protecting Public Health from Natural Gas Infrastructure," that recognizes the potential

[2049] Amy Townsend-Small et al., "Integrating Source Apportionment Tracers into a Bottom-up Inventory of Methane Emissions in the Barnett Shale Hydraulic Fracturing Region," *Environmental Science & Technology* 49, no. 13 (2015): 8175–82, https://doi.org/10.1021/acs.est.5b00057.
[2050] Kyle Adams, "Schoharie County Officials Ask New Studies on Gas Lines," *The Daily Gazette*, July 1, 2015, https://dailygazette.wufoo.com/forms/k1mmje2u1rvcynr/.
[2051] Ayana R. Anderson, "Health Effects of Cut Gas Lines and Other Petroleum Product Release Incidents — Seven States, 2010–2012," *Morbidity and Mortality Weekly Report* 64, no. 22 (June 12, 2015): 601–5.
[2052] American Medical Association, "H-135.930 Protecting Public Health from Natural Gas Infrastructure, Resolution 519, A-15," 2015, https://www.ama-assn.org/sites/default/files/media-browser/public/hod/a15-hod-resolutions.pdf.

impact to human health and the environment of natural gas pipelines and calls for a governmental assessment of these risks.[2053]

- March 3, 2015 – Researchers with the Southwest Pennsylvania Environmental Health Project measured ambient levels of particulate and volatile air pollutants from fracking-related operations and calculated expected human exposures in Washington County, Pennsylvania. Extremely high exposures peaked at night when air was still. These fluctuating exposure events mimic, in frequency and intensity, the episodic nature of health complaints among residents. Over a one-year period, compressor stations were responsible for more extreme exposure events (118) than well pads or gas processing plants.[2054]

- February 24, 2015 – As part of a literature review on the health impacts of compressor stations, the Southwest Pennsylvania Environmental Health Project reported that peak emissions of fine particles tended to occur during construction time, that day-to-day emissions during operational time can fluctuate greatly, and that a compressor blowdown typically represented the single largest emission event during operations. Hence, documentation of these fluctuations cannot be captured by calculating yearly averages. A blowdown is an intentional or accidental release of gas through the blowdown valve that creates a 30- to 60-meter-high gas plume. Blowdowns, which are used to release pressure, can last as long as three hours. The authors noted that blowdowns result in periods of high levels of volatile organic compound releases and that anecdotal accounts associate blowdowns with burning eyes and throat, skin irritation, and headache.[2055] There is neither a national or state inventory of compressor station accidents nor a body of peer-reviewed research on the public health impacts of compressor stations.

- February 17, 2015 – A Boston study found that emissions from residential, end-use natural gas infrastructure was a significant source of atmospheric methane—two to three times larger than previously presumed—and accounted for 60 to 100 percent of methane, depending on the season. Of all the natural gas in the downstream component of the natural gas system, 2.7 percent was lost to the atmosphere.[2056]

- February 10, 2015 – A team of engineers from Pennsylvania and Colorado examined methane emissions from natural gas compressor stations and found that vents, valves, engine exhaust, and equipment leaks were also major emissions sources. There was

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[2053] Medical Society of the State of New York, "2015 House of Delegates Actions: Public Health and Education," 2015, http://www.mssny.org/Documents/HOD/Actions/ActionPHE.pdf.
[2054] David R. Brown, Celia Lewis, and Beth I. Weinberger, "Human Exposure to Unconventional Natural Gas Development: A Public Health Demonstration of Periodic High Exposure to Chemical Mixtures in Ambient Air," *Journal of Environmental Science and Health, Part A* 50, no. 5 (2015): 460–72, https://doi.org/10.1080/10934529.2015.992663.
[2055] Southwest Pennsylvania Environmental Health Project, "Summary on Compressor Stations and Health Impacts," February 24, 2015, https://sape2016.files.wordpress.com/2014/01/summary_report_compressor_stations_swpaehp.pdf.
[2056] Kathryn McKain et al., "Methane Emissions from Natural Gas Infrastructure and Use in the Urban Region of Boston, Massachusetts," *Proceedings of the National Academy of Sciences* 112, no. 7 (2015): 1941–46, https://doi.org/10.1073/pnas.1416261112.

considerable variation in emissions among the 45 compressor stations measured. Surprisingly, substantial emissions were found even when compressors were not operating.[2057]

- December 27, 2014 – A *Pittsburgh Tribune-Review* investigation found that the vast majority of natural gas "gathering lines"—pipelines that take natural gas from rural well pads to processing plants—were regulated by neither federal nor state pipeline safety laws. The United States has nearly 230,000 miles of natural gas gathering lines that are unregulated, operating without safety standards or inspection. These pipelines are among the largest and highest-pressure pipes in use and carry gas at nearly three times the pressure of transmission lines, which transport the gas from the processing plants to urban distribution networks.[2058]

- November 11, 2014 – An analysis by a Carnegie Mellon University research team of 40,000 pipeline accidents from 1968 to 2009 found that comparatively few accidents accounted for a large share of total property damage, whereas a large share of fatalities and injuries were caused by numerous, small-scale accidents. There are 2.4 million miles of natural gas pipeline in the United States and 175,000 miles of hazardous liquid pipeline (which includes crude oil).[2059]

- October 30, 2014 – A research team led by David O. Carpenter at University at Albany found high levels of formaldehyde near 14 compressor stations in three states. In Arkansas, Pennsylvania, and Wyoming, formaldehyde levels near compressor stations exceeded health-based risk levels. The authors noted that compressor stations can produce formaldehyde through at least two routes: it is created as an incomplete combustion byproduct from the gas-fired engines used in compressor stations. It is also created when fugitive methane, which escapes from compressor stations, is chemically converted in the presence of sunlight. Formaldehyde is a known human carcinogen. Other hazardous air pollutants detected near compressor stations in this study were benzene and hexane. One air sample collected near a compressor station in Arkansas contained 17 different volatile compounds. (See entry for October 30, 2014 in Air Pollution.)

- October 15, 2014 – In comments to FERC, New York's Madison County Health Department reviewed the literature on compressor station emissions and expressed concerns about associated health impacts, including documented correlations between health problems and residential proximity to compressor stations. It also reviewed health outcomes associated with exposures to chemicals known to be released from compressor stations, including VOCs, carbonyls and aldehydes, aromatics, and particulate matter. In addition, gas from fracking operations transiting through compressor stations may carry

[2057] R. Subramanian et al., "Methane Emissions from Natural Gas Compressor Stations in the Transmission and Storage Sector: Measurements and Comparisons with the EPA Greenhouse Gas Reporting Program Protocol," *Environmental Science & Technology* 49, no. 5 (2015): 3252–61, https://doi.org/10.1021/es5060258.
[2058] Mike Wereschagin, "Rural Gas Gathering Pipelines Kindle Concerns about Safety Laws | TribLIVE.Com," *Trib Live*, December 27, 2014, https://archive.triblive.com/news/rural-gas-gathering-pipelines-kindle-concerns-about-safety-laws/#axzz3NAHfzYF8.
[2059] Kyle Siler-Evans et al., "Analysis of Pipeline Accidents in the United States from 1968 to 2009," *International Journal of Critical Infrastructure Protection* 7, no. 4 (2014), https://doi.org/10.1016/j.ijcip.2014.09.002.

gaseous radon. The Health Department noted a troubling lack of information on the intensity, frequency, and duration of emission peaks that occur during the blowdowns and large venting episodes that are a normal part of compressor operations.[2060]

- September 16, 2014 – Noting the proximity of a proposed high-pressure pipeline to Indian Point Nuclear Facility, as well as the evidence linking compressor station emissions to negative health impacts, New York's Rockland County legislature adopted a resolution calling for a comprehensive Health Impact Assessment in regards to Spectra Energy's planned Algonquin Incremental Market (AIM) natural gas pipeline, compressor, and metering stations expansion project.[2061] This resolution follows on the heels of similar resolutions expressing health concerns about the AIM project from both Westchester and Putnam County legislatures.[2062, 2063]

- January 24, 2013 – A report prepared for the Clean Air Council by an independent consulting firm to evaluate air quality impacts from the Barto Compressor Station in Penn Township, Lycoming County, Pennsylvania predicted "large exceedances" of the nitrogen dioxide (NO_2) 1-hour NAAQS. Researchers used allowable emissions in the PA DEP permit, the 2006-2010 meteorological data and the latest EPA modeling guidance for the model's prediction. Three techniques were used, and for two of the techniques, NAAQS exceedances occurred within a mile of the plant. The report concluded, "NO_2 impacts from the Barto plant alone are very significant since its emissions cause large exceedances of the 1-hour NAAQS."[2064]

- July 14, 2011 – A Fort Worth air quality study assessed the impact of drilling and fracking operations, and ancillary infrastructure, on concentrations of toxic air pollutants in the city of Fort Worth, Texas. The study found that compressor stations were a significant source of fracking-related air pollution. The compressor engines were responsible for over 99 percent of the hazardous air pollutants emitted from compressor stations, of which 67 percent was formaldehyde.[2065]

[2060] New York State Madison County Health Department, "Comments to the Federal Energy Regulatory Committee Concerning Docket No. CP14-497-000, Dominion Transmission, Inc," October 15, 2014.
[2061] Rockland County Legislature, "Resolution No. 404 of 2014 Urging That Health, Safety and Planning Concerns Be Addressed and Mitigated in the Environmental Review and All Other Review Processes before Project Permissions Be Granted for Spectra Energy's Algonquin Incremental Market (AIM) Natural Gas Pipeline, Compressor and Metering Stations Expansion Project," September 16, 2014, https://sape2016.files.wordpress.com/2014/05/rockland-aim-resolution.pdf.
[2062] Board of Legislators County of Westchester, State of New York, "Resolution RES-2014-80 Algonquin Incremental Marketing Project Resolution," July 21, 2014, https://sape2016.files.wordpress.com/2014/05/080414-wcbol-resolution-no-80-2014-requesting-due-diligence-on-environment-p.pdf.
[2063] Putnam County Legislature, "Resolution #104, Resolution Regarding the Algonquin Incremental Market (AIM) Project," May 9, 2014, https://sape2016.files.wordpress.com/2014/05/putnam-county-resolutions-104-163-and-182-1.pdf.
[2064] Khanh T. Tran, "AERMOD Modeling of NO2 Impacts of the Barto Compressor Station," Final Report (AMI Environmental, January 24, 2013), https://crawler.dep.state.pa.us/Air/AirQuality/AQPortalFiles/Regulations%20and%20Clean%20Air%20Plans/AERMOD%20NO2%20Modeling%20of%20Barto%20Compressor%20Station%20-%20Jan%2024%202013.pdf.
[2065] Eastern Research Group, "Fort Worth Natural Gas Air Quality Study Final Report," July 14, 2011, https://www.fortworthtexas.gov/departments/development-services/gaswells/air-quality-study/final.

Gas storage

Gas storage facilities include not only manmade holding tanks but also geological formations, most notably, aquifers, abandoned salt caverns, mines, and depleted oil fields left over from drilling operations. These unlined cavities were not created with the intent to store pressurized hydrocarbon gases, nor are they engineered for this purpose. Leakage from these facilities has resulted in water contamination, air pollution and explosions.

The 3,600-acre Aliso Canyon gas storage facility, located in a depleted oil field in southern California, released more than 100,000 metric tons of methane into the air of the San Fernando Valley over a four-month period beginning in October 2015 before it was finally contained in February 2016. This massive methane leak—the largest in U.S. history—is the greenhouse gas equivalent of a half million cars driving for a year. The plume itself was visible from space. More than 8,000 families in the nearby community of Porter Ranch were evacuated and relocated, thousands were sickened, and two public schools closed. As determined by a 2019 final report, the root cause of the Aliso Canyon blowout was a corroded well casing and lack of a shut-off valve in a half-century-old well.

Data released in 2018 reveal that there are more than 10,000 Aliso-style storage wells with gas flowing through only a single unprotected pipe—that is, with a single point of failure. Of the nearly 400 natural underground storage facilities in the United States, 296 of them have one or more of these wells, and they are located in 32 states. Many natural gas storage facilities approached capacity in 2020 as low demand and low prices created an enduring supply glut.

While not as common as depleted oil fields, salt cavern gas storage facilities suffer a disproportionate number of serious problems, including loss of cavern integrity and consequent gas migration.

- May 20, 2021 –Nova Scotia's geology includes salt formations along the Shubenacadie River where Alton Gas is proposing to build a gas storage facility. Despite a centuries-old treaty which gives the indigenous Mi'kmaq people rights to this land and river, they were not consulted during the permitting process. Mi'kmaq elders objecting to the construction predict certain destruction of land and river life from construction and maintenance of the gas storage facility. Critics also fear dire safety issues for indigenous women living in the area and along the 85-mile corridor that is proposed to connect the storage facility to the proposed LNG terminal 85 miles away."[2066]

- April 30, 2021 – A $25 million public health research study on impacts of the 2015 gas leak at Aliso Canyon is the result of a $120 million settlement between Southern Gas California Co., Los Angeles County, the City of Los Angeles, and the state agencies. The

[2066] Karen Edelstein, "Gas Storage Plan vs. Indigenous Rights in Nova Scotia" (FracTracker Alliance, May 20, 2021), https://www.fractracker.org/2021/05/gas-storage-plan-vs-indigenous-rights-in-nova-scotia/.

Los Angeles *Daily News* reported widespread community dissatisfaction with the direction of the study, which was spearheaded by the public health department with guidance from a scientific oversight committee and a community advisory group (CAG). The public health department released a study draft identifying key areas the health study should address, which the CAG has described as too broad and underdeveloped. "The CAG unanimously agrees that the loose draft language of the study's goals and priorities invites a mediocre study by encouraging the use of data proxies and environmental abstractions," said Craig Galanti, a member of CAG. Criticizing a reliance on publicly available, utility-derived data for a modeling study, the group cited a 2018 report by the California Council on Science and Technology which concluded that such air quality monitoring missed the first few days of the blowout, when exposures to the highest concentrations likely occurred. In addition, the CAG expressed the need for a clinically-based, human-subject focused study. "CAG members say if the health study doesn't include the chemical list, a cancer surveillance study, accurate air monitoring and benzene exposure data, it wouldn't be complete."[2067]

- April 7, 2021 – A 2019 blowout of 100,000 cubic feet of natural gas from Southern California's Playa del Rey oilfield served as a reminder of the long legacy of fossil fuel extraction and storage on the west side of Los Angeles. Playa del Rey's sandstone formation thousands of feet underground holds natural gas in an operation similar to that of Aliso Canyon. Both storage fields, reported the *Los Angeles Times*, have a long history of leaks. Opposition to Playa del Rey's gas storage field is growing, including among elected officials, in the form of municipal resolutions to close the facility and a call from the Los Angeles County Board of Supervisors to study the feasibility of closure. Though it has less than three percent of the storage capacity of Aliso Canyon, 45,000 people live within a mile of Playa del Rey field, compared with 6,500 within a mile of Aliso. Four thousand people live directly above the Playa del Rey storage field. A 2019 Harvard study singled out the field as particularly risky. [See July 8, 2019 entry below.][2068]

- January 12, 2021 – A study of surface deformation caused by the convergence of multiple underground gas storage facilities focused on the increasing use of salt caverns for gas storage, and resultant changes in pressure inside those caverns due to injection, unloading, and additional leaching. These can cause significant cavern disruption which can lead to deformation and subsidence. The study described an effective multi-parameter method for determining changes in rock mass deformation for salt caverns, as well for predicting the surface deformation for a large field of salt caverns.[2069]

- October 28, 2020 – Using Bayesian analysis, researchers calculated the frequency of accidents, incidents, failures, and other problematic events at U.S. underground natural

[2067] Olga Grigoryants, "Residents, Activists Express No Confidence in L.A. County's Aliso Canyon Gas Leak Health Study," *Los Angeles Daily News*, April 30, 2021, https://www.dailynews.com/2021/04/30/residents-activists-express-no-confidence-in-l-a-countys-aliso-canyon-gas-leak-health-study/.
[2068] Sammy Roth, "The Next Aliso Canyon Could Happen on L.A.'s Westside," *Los Angeles Times*, April 7, 2021, https://www.latimes.com/business/story/2021-04-07/aliso-canyon-natural-gas-playa-del-rey.
[2069] Krzysztof Tajduś et al., "Surface Deformations Caused by the Convergence of Large Underground Gas Storage Facilities," *Energies* 14, no. 2 (2021), https://doi.org/10.3390/en14020402.

gas storage facilities for each of the 31 states that host such facilities. Depleted oil and gas fields, which are, by far, the most common type of underground gas storage facility in the United States and have been in operation for the longest time, showed the highest number of problematic occurrences. Aquifer storage, though not as common, has led to contamination of drinking water wells on neighboring properties. Many occurrences have been linked with salt-cavern storage over a relatively small number of facility-years, and these include serious problems such as loss of cavern volume, loss of cavern integrity, gas migration into adjacent brine caverns, and elevated cavern pressures, which can endanger surface wellheads and related infrastructure of the brine caverns. "States having the largest number of occurrences at the lowest, nuisance-group level of severity are California and Pennsylvania (for oil-and-gas storage), Iowa and Illinois (for aquifer storage), and Texas (for salt-cavern storage)." [See also entry below for November 5, 2019.][2070]

- July 29, 2020 – A natural gas storage facility exploded in Mont Belvieu, Texas after a contractor struck an underground pipeline.[2071] The facility belonging to Lone Star NGL, a subsidiary of Dallas-based Energy Transfer LP, stores and processes natural gas liquids, including propane, butane and ethane. Five hundred and thirty-five miles of pipeline from the Permian Basin, Barnett Shale and East Texas transport natural gas liquids to the Mont Belvieu storage and fractionation facility. A company spokeswoman said that the company planned an investigation.

- June 30, 2020 – SoCalGas executives sought to delay by six months the next round of mechanical integrity tests on wells used to access the Aliso Canyon gas storage field, site of the 2015 four-month blowout releasing 100,000 metric tons of methane.[2072] These tests were required after a root cause analysis had determined that the blowout was caused by a faulty well casing at the facility, linked to microbial corrosion caused by contact with groundwater. (See entry for May 16, 2019.) California regulators instituted new regulations following the disaster, including the requirement that all wells undergo mechanical integrity tests at least once every two years. SoCalGas asked the state to suspend the requirement, citing the pandemic. The request was denied.

- June 9, 2020 – Use of the SoCalGas Aliso Canyon gas storage field has vastly expanded during California Governor's Newsome's tenure, despite a stated commitment to close the facility following the 2015 massive blowout.[2073] SoCalGas withdrew 20 billion cubic

[2070] Richard A. Schultz and David J. Evans, "Occurrence Frequencies and Uncertainties for US Underground Natural Gas Storage Facilities by State," *Journal of Natural Gas Science and Engineering* 84 (2020), https://doi.org/10.1016/j.jngse.2020.103630.
[2071] Julian Gill and Erin Douglas, "Natural Gas Storage Facility Explodes in Mont Belvieu," *Houston Chronicle*, July 29, 2020, sec. Houston, https://www.houstonchronicle.com/news/houston-texas/houston/article/Explosion-reported-at-Mont-Belvieu-industrial-15444117.php.
[2072] Sammy Roth, "Remember the Aliso Canyon Disaster? SoCalGas Just Tried to Delay Safety Tests," *Los Angeles Times*, June 30, 2020, sec. Climate & Environment, https://www.latimes.com/environment/story/2020-06-30/remember-the-aliso-canyon-disaster-socalgas-just-tried-to-delay-safety-tests.
[2073] Sammy Roth, "SoCalGas Ramps up Use of Aliso Canyon, Site of Worst Gas Leak in U.S. History," *Los Angeles Times*, June 9, 2020, sec. Climate & Environment, https://www.latimes.com/environment/story/2020-06-09/socalgas-ramps-up-use-of-aliso-canyon-site-of-worst-gas-leak.

feet of gas from the facility in winter 2019-2020, up from 14 billion the winter before, and one billion in 2017-2018. "The more the gas company uses the storage field, the higher the risk of additional leaks," said USC engineering professor Najmedin Meshkati, who authored a study examining the causes. (See December 1, 2017 entry.)

- May 20, 2020 – The *Texas Observer* reported on threats to the state's drinking water from changing oil and gas storage practices in Texas during a time of supply glut, negative prices for oil, and a growing scarcity of Gulf Coast storage tank capacity. As producers sought to store their excess oil and gas in underground salt caverns, in the same way the U.S. Strategic Petroleum Reserve stores their crude, the Texas Railroad Commission, which regulates oil and gas producers in that state, granted permission for such storage up for to five years. Commissioners also lifted the requirement to hold public hearings. Environmental groups and scientists decried the absence of formal opportunity for public comment, particularly concerned about the threat to the nine aquifers across Texas, which provide 60 percent of the state's water and underlie the oil fields. "Is it going to stay there and not leak into the aquifer?…The environmental concerns are the biggest issue here," according to Ramanan Krishnamoorti, petroleum engineer at the University of Houston.[2074] The agency's history of indifference toward potential contamination of aquifers is longstanding. "In 2014, the commission sided with Marathon Oil Company when a local groundwater conservation district raised concerns about the company injecting drilling waste into a productive South Texas aquifer. In its most recent annual report on groundwater contamination in Texas, a group of state agencies tasked with studying the issue found roughly 630 cases of groundwater contamination linked to 'total petroleum hydrocarbons' in 2018." *The Observer* noted that another risk of gas and oil storage in salt caverns is explosion. One such accident in 1992 in Brenham, TX killed a six-year-old boy and injured 13 others.

- May 18, 2020 – Gas storage has reached capacity as natural gas exceeds demand, and prices plummet, according to *Oilprice.com.*[2075] In Europe as in the United States, these trends have been exacerbated by mild weather in winter 2019-2020, more renewable energy production, and a crash in industrial demand for gas amid the pandemic. Although prospects for gas are better than oil because of the electrical generation industry, demand for gas will continue to decrease significantly if Europe embraces a green recovery and renewable energy sources are pressured to expand.

- April 15, 2020 – Using advanced remote sensing and in situ observations of near-surface atmospheric methane combined with wind data, researchers studied twelve active underground gas storage facilities in California, including Aliso Canyon, between January 2016 and November 2017 to determine net annual methane emissions.[2076] The

[2074] Christopher Collins, "With Storage Space Evaporating, the Oil and Gas Industry Will Get to Put Its Products Back Underground," *The Texas Observer*, May 20, 2020, https://www.texasobserver.org/underground-storage-oil-rule-rollback/.
[2075] Irina Slav, "Natural Gas Drillers Face Price Meltdown As Storage Fills Fast," *OilPrice.Com*, May 18, 2020, https://oilprice.com/Energy/Crude-Oil/Natural-Gas-Drillers-Face-Price-Meltdown-As-Storage-Fills-Fast.html.
[2076] Andrew K Thorpe et al., "Methane Emissions from Underground Gas Storage in California," *Environmental Research Letters* 15, no. 4 (2020): 045005, https://doi.org/10.1088/1748-9326/ab751d.

team, consisting of scientists from CalTech, Stanford, Lawrence Berkeley National Laboratory, and other institutions, said their "analysis reveals significant discrepancies with the State's accounting of UGS emissions as well as under reporting by individual facilities which if unresolved could impede efforts to meet future mitigation targets," and they found this conclusion to be consistent for both of their estimation techniques. The study's 2016 estimations of net annual methane emissions for the seven facilities that did report were approximately five times higher than they reported. Methane has been targeted for emissions mitigation by the State of California, including legislation focused on natural gas leak detection and repair and identification of emission hotspots. This study's findings included that, even since the massive Aliso Canyon release, researchers found persistent venting from the shutdown stack and episodic venting from equipment. Results from other facilities included highly variable emissions, and this variability "remains one of the most challenging aspects of UGS emissions quantification, underscoring the need for more systematic and persistent methane monitoring."

- April 10, 2020 – Ethane, a byproduct of fracked shale gas and needed to produce plastics, is often stored in underground caverns. Cracker plants, which would use the ethane, are being constructed and proposed along the Ohio River around Pittsburgh, Pennsylvania, to use the wet fracked gas from Pennsylvania and Ohio. A 2017 an Appalachian Oil and Natural Gas Research Consortium study identified regions in West Virginia, Pennsylvania, and Ohio for constructing caverns in underground salt beds or limestone rock, as well as in abandoned gas fields, for storing natural gas liquids. An *Inside Climate News* piece provided this background, as well as the mechanics of underground gas storage, for examining the history and hazards of Mont Belvieu, 30 miles northeast of Houston, the world's largest natural gas liquids underground storage area.[2077] Mont Belvieu has a history of environmental calamities, and the complex's operator continues to be the target of enforcement actions. In view of that history, the Ohio River underground storage facilities are being promoted as very different from the accident-prone and violation-ridden Mont Belvieu. "We just want to be a warehouse," said David Hooker, president of Mountaineer NGL Storage, which is developing a site along the Ohio River in Monroe County.

- March 24, 2020 – In 2016 Nova Scotia's environment minister, Margaret Miller, permitted a gas storage facility on the banks of the Shubenacadie River. Alton Gas, a subsidiary of Calgary-based energy company AltaGas, proposed to store up to 10 billion cubic feet of natural gas in underground caverns. The Sipekne'katik First Nation sued to stop the project both because it is Aboriginal land and because the process would cause significant pollution of the river. The storage cavern would be created by flushing nearby salt deposits with water from the Shubenacadie River. As reported by the CBC, the Nova

[2077] James Bruggers, "For the Ohio River Valley, an Ethane Storage Facility in Texas Is Either a Model or a Cautionary Tale," *Inside Climate News*, April 10, 2020, https://insideclimatenews.org/news/10042020/ethane-plant-appalachia-mont-belvieu-texas/.

Scotia Supreme Court agreed to a delay of at least 120 days and has ordered the province to resume consultations with Sipekne'katik First Nation.[2078]

- March 20, 2020 – In 2016, Congress passed the Protecting our Infrastructure of Pipelines and Enhancing Safety (PIPES) Act requiring the U.S. Department of Transportation's Pipeline and Hazardous Materials Safety Administration (PHMSA) to promulgate underground natural gas storage safety regulations following the massive 2015 Aliso Canyon gas leak. In February 2020, PHMSA issued its Final Rule, which weakened existing safety regulations applicable to underground natural gas storage facilities, including limiting the type of accidents or routine maintenance activities that had previously been deemed reportable. Only well plugging or abandonment or maintenance costing more than $200,000 now require reporting to PHMSA. According to the legal news digest, *JD Supra*, "the Final Rule provides clarifications to the Interim Final Rule in ways that should benefit storage operators," and the agency resisted in its rule "calls to impose additional safety requirements on storage operators at least for the foreseeable future."[2079]

- January 24, 2020 – Porter Ranch residents presented in Superior Court the damages they sustained from the massive Aliso Canyon gas storage site gas leak and the actions they would have taken to protect themselves and their property if SoCalGas had not delayed in notifying authorities and residents. A state appeals court panel had ruled that residents were entitled to this hearing addressing "whether petitioners can prove damages from the three-day delay in reporting the leak, as charged in the criminal complaint." At 2016 settlement talks between prosecutors and SoCalGas, residents complained of not being part of the proceedings and left unable to seek restitution. Many residents are still sick and property still contaminated, according to the residents' attorney.[2080]

- January 7, 2020 – *NBC Los Angeles* reported that Los Angeles County Board of Supervisors unanimously called on California Governor Gavin Newsom to expedite the closure of the Aliso Canyon natural gas storage facility in Porter Ranch, site of the largest methane leak in U.S. history.[2081] Supervisor Kathryn Barger said, "We do not know what the long-term impacts of the gas leak will be… The only way to preserve the health and safety of the residents around Aliso Canyon is for it to close." Operator of the site, SoCalGas continued to maintain that the site is needed to provide an affordable electric energy supply. Fearing expansion at another SoCalGas storage facility in the Los Angeles

[2078] Taryn Grant, "Siding with First Nation, N.S. Judge Overturns Alton Gas Approval | CBC News," *CBC*, March 24, 2020, https://www.cbc.ca/news/canada/nova-scotia/alton-gas-nova-scotia-supreme-court-appeal-decision-1.5508130.
[2079] James Bowe Jr. and William Rice, "PHMSA Issues Final Rule on Underground Natural Gas Storage Safety Establishing a Phased-in, Multi-Year Timeframe for Integrity Management," *JD Supra*, March 21, 2020, https://www.jdsupra.com/legalnews/phmsa-issues-final-rule-on-underground-60203/.
[2080] Tom Bray, "Aliso Canyon Gas Leak Victims Argue for Restitution; No Ruling Yet," *Daily News*, January 24, 2020, https://www.dailynews.com/2020/01/24/aliso-canyon-gas-leak-victims-argue-for-restitution-no-ruling-yet.
[2081] City News Service, "LA County Calls on Governor to Expedite Closure of Aliso Canyon," *NBC Los Angeles*, January 7, 2020, https://www.nbclosangeles.com/news/local/la-county-calls-on-governor-to-expedite-closure-of-aliso-canyon/2286869/.

area, a Supervisor successfully added an amendment to the Board's call to the governor, requesting a feasibility study of closing the Playa del Rey facility.

- November 19, 2019 – California Governor Gavin Newsom called on California's utilities regulator to identify ways to accelerate the pace to state reliance on renewables, with the objective of closing the Aliso Canyon gas storage facility. Renewable energy sources like solar and wind play increasing roles in California's energy landscape, but natural gas still accounts for the largest single source of in-state generation, at 46.5 percent. Environmental groups criticized the Governor's call for additional study, citing an independent energy consulting group's finding that natural gas injections at Aliso Canyon were not needed in the short-term. For the long-term, the report said that advances in energy efficiency and carbon-free storage will make Aliso Canyon obsolete. At the time of this San Diego *Tribune* report, Aliso Canyon gas storage was permitted at about 39 percent of maximum capacity, after the initial resumption in July 2017.[2082]

- November 5, 2019 – The first probabilistic analysis of natural gas accidents—variously referred to as events, incidents, accidents, or failures across studies—at underground gas storage facilities in the United States found in its review an occurrence rate "larger than has been previously reported."[2083] The researchers predicted, "The probability of one serious or catastrophic leakage occurrence to the ground surface within the next 10 years, assuming constant number of facilities, is approximately 0.1–0.3% for any facility type." Using a Bayesian statistical approach, an inference method that integrates new data with existing knowledge, researchers said that their study "demonstrates the value of collecting new historical data for occurrences as well as comparing the newly acquired data to earlier databases." The study's characterization of risks to plan improved risk management and regulatory policy of underground gas storage facilities included cause, severity, and uncertainty for depleted oil-and-gas field storage, aquifer storage, and solution-mined salt cavern storage. Depleted oil-and-gas field storage showed the largest probabilities and the smallest uncertainties for accidents.

- October 15, 2019 – As the October 2019 Saddleridge Fire burned and a fire broke out and burned for 24 hours next to the Aliso Canyon gas storage facility, residents of Porter Ranch, California prepared for mandatory evacuation, *Knock LA* reported.[2084] Since and before the oil field was repurposed for gas storage in 1973, fires have been frequent at and around the facility, some caused by ruptured gas lines and others triggered by earthquakes. Although the local department of health failed to warn residents to wear respirator masks until 12 hours after the evacuation, a physician in the area advised residents to use respirators for protection against particulate matter that included not only

[2082] Rob Nikolewski, "Newsom Looks to Accelerate Time Line for Closing Aliso Canyon Natural Gas Facility," *San Diego Union-Tribune*, November 20, 2019, sec. Energy, https://www.sandiegouniontribune.com/business/energy-green/story/2019-11-19/newsom-looks-to-accelerate-time-line-for-closing-aliso-canyon-natural-gas-facility.
[2083] Richard A. Schultz et al., "Characterization of Historical Methane Occurrence Frequencies from U.S. Underground Natural Gas Storage Facilities with Implications for Risk Management, Operations, and Regulatory Policy," *Risk Analysis* 40, no. 3 (2020): 588–607, https://doi.org/10.1111/risa.13417.
[2084] Patty Crost Glueck, "As The North SFV Burns, Worries About The Aliso Canyon Gas Storage Facility Ignites," *Knock LA*, October 15, 2019, https://knock-la.com/as-the-north-sfv-burns-worries-about-the-aliso-canyon-gas-storage-facility-ignites-ec12a3b38027/.

soot from burned vegetation, but also from burning contaminants released during the Aliso Canyon blowout. The piece referenced the recent study (See Jun 26, 2019 entry below) that found "a broad range of hazardous air pollutants (HAPs)" co-emitted during the Aliso Canyon blowout and during "final well kill attempts." Two deaths were reported in the aftermath of the fire: that of a park ranger and a Porter Ranch resident, both of heart attacks, known health consequences of particulate matter exposure.

- July 31, 2019 – A *ProPublica* investigation explored the political connections behind the proposed Appalachian Storage and Trading Hub, a $10 billion dollar mammoth underground storage facility for ethane and other byproducts used in plastics manufacturing.[2085] West Virginia state officials see the reserves that form the largest natural gas field in the world as "a path to renewed political and economic relevance for the Mountain State, which they envision rivaling the Gulf Coast as a center for processing natural gas and producing plastics." However, such a large facility is beyond what the region could support and carries a range of risks. West Virginia leaders sought a $1.9 billion federal loan guarantee, one of the largest ever considered, and which could leave taxpayers on the hook in the event the project fails, as well as looking to the federal government for a "streamlined" review process. The hub's prospects were considered weakened by "uncertainty and turmoil" of the U.S.-China trade war.

- July 8, 2019 – Tens of thousands of U.S. homes and residents are located within a proposed underground gas storage (UGS) "Wellhead Safety Zone" of active UGS wells, according to a multi-institution study comparing methods of estimating this hazard.[2086] In some cases homes and residents were within a state's oil and gas well surface setback distance. Lead author Drew Michanowicz, of the Center for Climate, Health and Global Environment at the Harvard T.H. Chan School of Public Health said to *West Virginia Public Radio*, "Our results were somewhat surprising in that a lot of these wells are in residential suburban areas, which in terms of the entire natural gas supply chain is definitely a unique kind of land use conflict."[2087] The researchers applied a new method of allocating an average person per household to geospatially-identified residential housing unit. This new method showed 65 percent of UGS wells occupying residential urban and suburban areas, and across the six states studied, 41 percent of underground storage wells were located within one city block of at least one home. As reported by *West Virginia Public Radio*, "in Ohio, more than half of the state's underground storage wells are located within one block of a residence" and "affected an estimated 12,000 Ohio homes and over 30,000 residents." The new method provided more precise estimates than the previous standard method, but by either benchmark, there is "a substantial degree of land use conflict between populations and UGS wells" in Ohio.

[2085] Keith Schneider, "West Virginia Bets Big on Plastics, and on Backing of Trump Administration," *ProPublica*, 2019, https://www.propublica.org/article/appalachian-storage-and-trading-hub-ethane-west-virginia-plastics-backing-of-trump-administration.

[2086] Drew R. Michanowicz et al., "Population Allocation at the Housing Unit Level: Estimates around Underground Natural Gas Storage Wells in PA, OH, NY, WV, MI, and CA," *Environmental Health* 18, no. 1 (December 2019): 58, https://doi.org/10.1186/s12940-019-0497-z.

[2087] Brittany Patterson, "Study Finds Thousands Live Near Underground Natural Gas Storage Wells," *WVPB*, July 9, 2019, sec. WVPB News, https://www.wvpublic.org/news/2019-07-09/study-finds-thousands-live-near-underground-natural-gas-storage-wells.

- Jun 26, 2019 – Scientists from the United Kingdom, China, and the United States conducted a study of links between particulate matter (PM), hazardous air pollutants (HAPS), and methane emissions, during the Aliso Canyon gas storage facility blowout.[2088] Samples obtained during the massive methane release showed a unique gas and particle concentration in ambient air and a characteristic "fingerprint" of metals in the indoor dust samples, similar to samples taken at the blowout site. These analyses, together with health surveys of several households, provided plausible explanations for health symptoms that persisted post-remediation. Various kill-well attempts were a source of multiple toxic air pollutants, such as various sizes of PM and volatile organic compounds (VOCs). Of note in their analyses, the researchers found that long-term averaged HAPs levels were normal, but short samplings, such as the individual 5-minute "trigger" samples, identified elevated concentrations, several above health benchmarks. Speaking to *CleanTechnica*, lead author UCLA environmental health scientist Diane A. Garcia-Gonzales said, "Our findings demonstrate that uncontrolled leaks or blowout events at natural gas storage facilities can release pollutants with the potential to cause not only environmental harm, but also adverse health consequences in surrounding communities."[2089] Adding to the complicated picture, researchers lacked baseline measurements, the full range of toxins emitted during the active blowout may not have been sampled, and the study may not have addressed all potentially biologically relevant pollutants; elevations in HAPs benzene, known to cause cancer, and hexane and xylene, neurotoxins also harmful to human health, all correlated with elevated methane levels.

- May 16, 2019 – A root cause analysis of the 2015 Aliso Canyon blowout determined that surface corrosion on the outside of well casing was the immediate cause of the disaster that sent uncontrolled releases of methane into the air for 111 days. Prolonged contact with groundwater and microbes, most likely methanogenic Archaea, was the underlying cause of the corrosion. Additional contributing factors identified in this final report include lack of detailed follow-up investigations after other failure events in the Aliso Canyon storage field; lack of investigations following the discovery of corrosion in other wells; lack of any form of risk assessment focused on wellbore integrity management; lack of understanding of groundwater depths; and lack of a dual mechanical barrier system in the wellbore.[2090]

- February 1, 2019 – An assessment of gas leakage from different types of natural gas storage facilities that established a mathematical model to predict leakage points showed that long-term periodic injection of gas and improper construction will lead to some

[2088] Diane A. Garcia-Gonzales et al., "Associations among Particulate Matter, Hazardous Air Pollutants and Methane Emissions from the Aliso Canyon Natural Gas Storage Facility during the 2015 Blowout," *Environment International* 132 (2019): 104855, https://doi.org/10.1016/j.envint.2019.05.049.
[2089] Charles W. Thurston, "New Study Calls For Monitoring Old Oil & Gas Wells For Air Emissions," *CleanTechnica*, June 27, 2019, https://cleantechnica.com/2019/06/27/new-study-calls-for-monitoring-old-oil-gas-wells-for-air-emissions/.
[2090] Blade Energy Partners, "Root Cause Analysis of the Uncontrolled Hydrocarbon Release from Aliso Canyon, SS-25," Main Report, May 16, 2019, https://www.socalgas.com/sites/default/files/SoCalGas-75-Served-03-15-21.pdf.

degree of gas leakage risks, no matter what kind of construction process is used to create the gas storage reservoir.[2091]

- December 17, 2018 – Plans by Alton Natural Gas to create a massive gas storage hub in salt caverns north of Halifax, Nova Scotia were delayed due to "project and regulatory planning," and the company has asked the Nova Scotia Utility and Review Board to extend its cavern construction permit. The plan involves hollowing out underground salt deposits using water from the tidal Shubenacadie River. The brine waste would then be dumped into the river, twice a day at high tide, over a two- to three-year period. Members of the Sipekne'katik First Nation argue that the project will harm the ecology of the tidal river, which runs through the middle of Nova Scotia. They have continuously occupied and protested at the site since 2014.[2092]

- August 20, 2018 – A research team investigated the geomechanics of an underground natural gas storage facility in China. They noted that geological factors and engineering factors can both contribute to leaks. Engineering factors include problems with casing integrity, cementing quality, and salt cavern operating pressure. Geological factors include challenges posed by the complexity of geological formations, imperfect sealing by the caprock, and the presence of faults. Using geological analysis, permeability tests, and CT scans, the authors determined that the risk of leakage in this salt cavern underground gas storage arises mainly from a failure of wellbore tightness within a mudstone interlayer.[2093]

- July 12, 2018 – The New York State Department of Environmental Conservation denied a permit for liquified petroleum gas storage (propane) in abandoned salt caverns on the shoreline of Seneca Lake. "The record demonstrates that the impacts of this project on the character of the local and regional community, including but not limited to the environmental setting and sensitivity of the Finger Lakes area and the local and regional economic engines (e.g., wine, agricultural and tourism industries), are significant and adverse and the project does not avoid or minimize those impacts to the maximum extent practicable. Furthermore, the significant adverse impacts on community character are not outweighed or balanced by social, economic or other considerations, and cannot be avoided or minimized to the maximum extent practicable by the proposed mitigation measures." Concerns were also raised about the structural integrity of the caverns following disclosure by the gas storage company that additional pressure testing in the

[2091] Xiao Wei and Zhang Zhichao, "Study on the Production Mode and Leakage Risk of Gas Storage Well Completion," *IOP Conference Series: Earth and Environmental Science* 233 (2019): 042007, https://doi.org/10.1088/1755-1315/233/4/042007.
[2092] Michael MacDonald, "More Delays for Underground Cavern Gas Storage Plan North of Halifax," *CBC*, December 17, 2018, https://www.cbc.ca/news/canada/nova-scotia/delays-underground-cavern-gas-storage-alton-natural-gas-1.4949423.
[2093] Xiangsheng Chen et al., "Study on Sealing Failure of Wellbore in Bedded Salt Cavern Gas Storage," *Rock Mechanics and Rock Engineering* 52, no. 1 (2019): 215–28, https://doi.org/10.1007/s00603-018-1571-5.

caverns would be required to assess possible leaks.[2094, 2095]The previous year, a subsidiary of the same company scrapped a parallel plan to expand the storage of natural gas in adjacent salt caverns along the lake shore.[2096]

- June 22, 2018 – A research team undertook an analysis to determine why the roof of China's first salt cavern underground gas storage facility collapsed, as determined by a sonar test after just 1.3 years of use. They concluded that the main reasons for the collapse were the large-span flat roof, a too-rapid decrease in internal gas pressure, and localized damage that led to massive collapse. They also concluded that this cavern has a high risk of roof collapse taking place again. The study includes evaluations of other similar incidents worldwide. Using geomechanical modeling, the authors developed a "new failure prediction index, consisting of volume shrinkage, dilatancy safety factors, displacement, vertical stress, and equivalent strain."[2097]

- May 4, 2018 – A new Department of Transportation rule requires gas companies that operate storage facilities to disclose information about design, leaks, and repairs of their wells. According to data released on April 4, 2018 as part of this rule, more than 10,000 wells have gas flowing through only a single unprotected pipe—that is, with a single point of failure. Of the nearly 400 natural underground storage facilities in the United States, 296 of them have one or more of these wells, and they are in 32 states.[2098] These statistics update an earlier estimate by Harvard University researcher Drew Michanowicz, who, consulting earlier databases, had pegged the number of Aliso-type wells at about 2,700.[2099] (See also entry for May 24, 2017.)

- March 6, 2018 – Illinois has the largest amount of natural gas storage in salt formations in the nation. Some of these storage sites underlie the Mahomet Aquifer, which provides drinking water for 14 counties in east-central Illinois. Prompted by an October 2016 report by a federal task force in the aftermath of California's Aliso Canyon natural gas leak, a team from the University of Illinois' Prairie Research Institute created an

[2094] State of New York Department of Environmental Conservation, "Finger Lakes LPG Storage, LLC - Decision of the Commissioner, Final Supplemental Environmental Impact Statement, and SEQRA Findings Statement, July 12, 2018," July 12, 2018, https://www.dec.ny.gov/hearings/114139.html.
[2095] Jeff Platsky, "Crestwood Acknowledges Possible Leaks in Proposed LPG Storage in Seneca Lake Mines," *Press & Sun-Bulletin*, May 21, 2018, https://www.pressconnects.com/story/news/local/2018/05/21/crestwood-seneca-lake-gas-storage/629768002/.
[2096] Jon Campbell, "Crestwood's Seneca Lake Propane Storage Facility Rejected by DEC," *Press & Sun-Bulletin*, July 12, 2018, https://www.pressconnects.com/story/news/2018/07/12/dec-rejects-plan-crestwood-propane-storage-facility-seneca-lake/779605002/.
[2097] Tongtao Wang et al., "Geomechanical Investigation of Roof Failure of China's First Gas Storage Salt Cavern," *Engineering Geology* 243 (2018): 59–69, https://doi.org/10.1016/j.enggeo.2018.06.013.
[2098] U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration, "Gas Distribution, Gas Gathering, Gas Transmission, Hazardous Liquids, Liquefied Natural Gas (LNG), and Underground Natural Gas Storage (UNGS) Annual Report Data | PHMSA," 2018, https://www.phmsa.dot.gov/data-and-statistics/pipeline/gas-distribution-gas-gathering-gas-transmission-hazardous-liquids.
[2099] Drew Michanowicz, "Op-Ed: The Aliso Canyon Gas Leak Was a Disaster. There Are 10,000 More Storage Wells out There Just like It," *Los Angeles Times*, May 14, 2018, sec. Opinion, https://www.latimes.com/opinion/op-ed/la-oe-michanowicz-aliso-canyon-gas-leak-20180514-story.html.

introductory guide to provide basic information about the Mahomet Aquifer and natural gas storage in east-central Illinois.[2100] (See also entry for October 18, 2016.)

- January 18, 2018 – The California Council of Science and Technology released a 910-page report analyzing the safety risks of all 14 facilities in the state that store gas in depleted oil fields. Among its findings: gas companies do not disclose the chemicals that are pumping underground; state regulators lack necessary information to assess risks; and many wells servicing the storage fields are 60 to 90 years old with no regulatory limit to the age of the well.[2101]

- December 1, 2017 – A University of Southern California-led team investigated the roots causes of the catastrophic Aliso Canyon gas storage blow-out, which began October 23, 2015 and continued for four months before being contained. Using methodology designed to capture both social and technological factors, the team concluded that corporate dysfunction and lack of government oversight were the driving forces responsible for the accident. "Risk analysis is vital for safe well operations and relies on analyzing prior data records, yet no national standards for well records were in place prior to the accident. There was no clear overarching agency that was in control of the accident's intervention and aftermath."[2102] In a subsequent news piece from the university, Najmedin Meshkati, senior author of the study, said, "SoCal Gas had lenient requirements for infrastructure record keeping, no comprehensive risk management plan, and no testing programs or plans in place to remediate substandard wells. The company needs to improve its safety culture."[2103]

- November 22, 2017 – The U.S. Government Accountability Office (GAO) reported that, two years after the Aliso Canyon blow-out, the Pipeline and Hazardous Materials Safety Administration (PHMSA) is failing to inspect natural gas storage sites in a timely manner, as called for by the Department of Transportation's interim standards. Until 2016, states set the standards for 211 of the nation's 415 gas storage sites, while the 204 sites that were connected to interstate pipelines had no standards at all. Collectively, these 415 natural gas storage sites contain about 17,000 wells that inject or withdraw natural gas from the underground formations below, which include depleted oil and gas

[2100] R. Locke et al., "An Introductory Guide to the Mahomet Aquifer and Natural Gas Storage in East Central Illinois" (Prairie Research Institute, 2018), https://www.ideals.illinois.edu/bitstream/handle/2142/99145/PRI%20Intro%20Guide%20to%20the%20Mahomet%20Aquifer%20and%20Natural%20Gas%20Storage_02.22.2018_printed.pdf?sequence=2&isAllowed=y.
[2101] Jane C. S. Long et al., "Long-Term Viability of Underground Natural Gas Storage in California: An Independent Review of Scientific and Technical Information," Technical Report (California Council of Science and Technology, January 18, 2018), https://ccst.us/reports/long-term-viability-of-underground-natural-gas-storage-in-california-an-independent-review-of-scientific-and-technical-information/.
[2102] Maryam Tabibzadeh et al., "A Systematic Framework for Root-Cause Analysis of the Aliso Canyon Gas Leak Using the AcciMap Methodology: Implication for Underground Gas Storage Facilities," *Journal of Sustainable Energy Engineering*, 2017, https://doi.org/10.7569/JSEE.2017.629515.
[2103] Zen Vuong, "Who Should Be Held Responsible for the Aliso Canyon Gas Leak?," *USC News*, February 15, 2018, https://news.usc.edu/136300/who-should-be-held-responsible-for-the-aliso-canyon-gas-leak/.

reservoirs, abandoned mines, depleted aquifers, and hard rock caverns. The GAO noted that more than 300 cities and towns are located near natural gas storage sites.[2104]

- June 21, 2017 – In response to requests from the oil and natural gas industry, the White House announced that it will delay implementation of a rule that would have set national standards for underground natural gas storage. Prompted by the 2015 disaster at Aliso Canyon and developed under the previous administration, this federal interim rule had called for phasing out single-point-of-failure, single-containment designs of the type that made impossible the task of swiftly shutting off the impaired Aliso Canyon well once it began leaking.[2105]

- May 24, 2017 – A national assessment of thousands of underground gas storage wells by a Harvard School of Public Health team found that more than 20 percent are similar in design to the well that failed at Aliso Canyon. These obsolete wells, with single failure points and a median age of 74 years, operate in 19 states and represent more than half of the working capacity for U.S. natural gas. More than 2,700 of these wells were not originally designed to hold gas and, as at Aliso Canyon, have been repurposed to do so. An estimated 210 of these repurposed wells (located in Pennsylvania, Ohio, New York, and West Virginia) are more than 100 years old and entirely lack cement zonal isolation methods. Study author Jonathan Buonocore said, "Partly because no federal safety regulations apply to natural gas storage wells or their operations (now pending), very little aggregate information was available. . . . After we identified this data gap, we realized we needed to build our own database to begin to assess this previously inapparent hazard." With the 50 percent increase in domestic natural gas production over the last ten years, natural gas storage is at an all time high and in demand.[2106, 2107]

- October 21, 2016 – The California Air Resources Board determined that the Aliso Canyon gas storage facility released 100,000 tons of methane, becoming the largest ever natural gas leak in U.S. history.[2108]

[2104] U.S. Government Accountability Office, "Natural Gas Storage: Department of Transportation Could Take Additional Steps to Improve Safety Enforcement Planning," Report to Congressional Requesters, November 22, 2017, https://www.gao.gov/assets/690/688553.pdf.
[2105] Rich Nemec, "PHMSA Pauses Stricter Natural Gas Storage Rules for Clarification," *Natural Gas Intelligence*, June 21, 2017, sec. Regulatory, https://www.naturalgasintel.com/phmsa-pauses-stricter-natural-gas-storage-rules-for-clarification/.
[2106] Drew R Michanowicz et al., "A National Assessment of Underground Natural Gas Storage: Identifying Wells with Designs Likely Vulnerable to a Single-Point-of-Failure," *Environmental Research Letters* 12, no. 6 (2017): 064004, https://doi.org/10.1088/1748-9326/aa7030.
[2107] Institute of Physics, "Study Uncovers Widespread Leak Risk for US Underground Natural Gas Storage Wells," *Phys.Org*, May 24, 2017, https://phys.org/news/2017-05-uncovers-widespread-leak-underground-natural.html.
[2108] California Air Resources Board, "Determination of Total Methane Emissions from the Aliso Canyon Natural Gas Leak Incident | California Air Resources Board," October 21, 2016, https://ww2.arb.ca.gov/resources/documents/determination-total-methane-emissions-aliso-canyon-natural-gas-leak-incident.

- October 18, 2016 – A federal task force issued a report with 44 recommendations intended to prevent another Aliso Canyon-style disaster. Chief among them is a phase-out of "single-point of failure" designs.[2109]

- July 13, 2016 – As reported by the *Los Angeles Daily News,* Los Angeles County health officials were prepared to go to court to ensure that the Southern California Gas Company complies with an order to pay for professional comprehensive cleaning in the homes of residents who were relocated due to the Aliso Canyon gas leak. The company had filed legal papers asking that the order "to remove dust and oily mist from up to 35,000 homes be nullified," after their report of having cleaned 1,700 homes to date. The Los Angeles County Health Department said the company had done a poor job on these and did not follow protocol to remove the metal particles, including barium, manganese, vanadium, aluminum, and iron previously identified in household surface dust.[2110]

- July 9, 2016 – California's South Coast Air Quality Management District and Southern California Gas Company were still at an impasse seven months after the company was given an abatement order that included a community health study on the potential impacts of exposures from the massive Aliso Canyon leak. The company was ordered to commit to paying "reasonable costs" for the study.[2111]

- June 22, 2016 – The first federal legislation of gas storage facilities was signed into law. The Protecting our Infrastructure of Pipelines and Enhancing Safety Act of 2016 includes a provision in response to the Aliso Canyon gas leak requiring PHMSA to develop regulations for the construction and operation of underground natural gas storage facilities.[2112] (See entry below, of February 8, 2016, for analysis of the likely shortcomings of these first federal regulations and their inability to prevent a leak such as that at Aliso Canyon.)

- June 20, 2016 – As reported in *Geophysical Research Letters*, an airborne instrument onboard a NASA satellite was able to detect and quantify the size and shape of the methane plume from the Aliso Canyon gas leak as the event occurred.[2113] This is the first

[2109] U.S. Department of Energy and U.S. Department of Transportation's Pipeline & Hazardous Materials Safety Administration, "Ensuring Safe and Reliable Underground Natural Gas Storage: Final Report of the Interagency Task Force on Natural Gas Storage Safety," October 18, 2016, https://energy.gov/sites/prod/files/2016/10/f33/Ensuring%20Safe%20and%20Reliable%20Underground%20Natural%20Gas%20Storage%20-%20Final%20Report.pdf.
[2110] Susan Abram, "SoCalGas Slammed for Poor Cleanup of Porter Ranch Homes," *Daily News*, July 13, 2016, https://www.dailynews.com/health/20160713/socalgas-slammed-for-poor-cleanup-of-porter-ranch-homes.
[2111] Dana Bartholomew, "Gas Company, Pollution Agency at Odds over Cost of Porter Ranch Health Study," *Daily News*, July 9, 2016, https://www.dailynews.com/government-and-politics/20160709/gas-company-pollution-agency-at-odds-over-cost-of-porter-ranch-health-study.
[2112] Timothy Cama, "Obama Signs Pipeline Safety Bill," *TheHill*, June 22, 2016, https://thehill.com/policy/energy-environment/284479-obama-signs-pipeline-safety-bill.
[2113] D. R. Thompson et al., "Space-based Remote Imaging Spectroscopy of the Aliso Canyon CH_4 Superemitter," *Geophysical Research Letters* 43, no. 12 (2016): 6571–78, https://doi.org/10.1002/2016GL069079.

time a natural gas leak has been visible from space, according to the authors of the study.[2114]

- May 4, 2016 – Southern California Gas Company said that costs related to the Aliso Canyon natural gas storage facility leak reached an estimated $665 million. The utility company let the Securities and Exchange Commission know they carry policies with a combined limit available "in excess of $1 billion," but according to the *Los Angeles Times,* legal experts and lawyers said that $1 billion in insurance might not be enough for what they ultimately need.[2115]

- April 12, 2016 – California energy agencies issued a report indicating the threat of widespread summer power outages if no gas can be withdrawn from Aliso Canyon. The report was met with criticism. "Consumer groups and utility critics contend that the blackout warnings are an irresponsible scare tactic to ensure that Southern California Gas Company is allowed to keep storing gas at the facility and that ratepayers will pay for upgrades to store even more fuel there."[2116]

- April 6, 2016 – The *Los Angeles Times* reported that, though prices for homes in Porter Ranch adjacent to the Aliso Canyon gas storage leak held up, sales declined. After the leak that began October 23, 2015, sales from December 2015 to February 2016 declined 20 percent from the year before. Disclosures for homes in the area "now include a mention of the community's proximity to the gas field and the recent problems."[2117]

- March 18, 2016 – The California State Oil and Gas Division of the Department of Conservation issued penalties totaling $75,000 for three separate violations after finding incidents of intentional venting of gas at the Aliso Canyon gas field and malicious concealment of those acts. Both are violations of the state gas regulations.[2118] Following the Aliso Canyon gas storage leak, the California State Public Utilities Commission ordered a statewide survey of California's 12 natural gas storage fields and found 229 faulty valves, flanges and leaky wellheads and a 230th leak at an abandoned well; eight were deemed hazardous.[2119]

[2114] Chris Mooney, "This Gas Leak Was so Massive That NASA Saw It from Space," *Washington Post*, June 15, 2016, https://www.washingtonpost.com/news/energy-environment/wp/2016/06/15/this-gas-leak-was-so-massive-that-nasa-saw-it-from-space/.
[2115] Ivan Penn, "Costs Related to Aliso Canyon Leak Reach an Estimated $665 Million," *Los Angeles Times*, May 4, 2016, sec. Business, https://www.latimes.com/business/la-fi-aliso-canyon-costs-20160504-snap-story.html.
[2116] Ivan Penn, "'This Is a Threat. This Is Not a Report.' Critics Call Blackout Warnings a Scare Tactic to Keep Aliso Canyon Open," *Los Angeles Times*, April 12, 2016, sec. Business, https://www.latimes.com/business/la-fi-gas-field-20160412-story.html.
[2117] Andrew Khouri, "Gas Leak Disrupts Porter Ranch Housing Market," *Los Angeles Times*, April 6, 2016, sec. Real Estate, https://www.latimes.com/business/realestate/la-fi-porter-ranch-sales-20160406-story.html.
[2118] California Department of Conservation, "State Oil & Gas Division Issues $75,000 Fine to Operator for Illegally Venting Natural Gas," March 18, 2016, http://www.conservation.ca.gov/index/Documents/2016-06%20DOC%20fines%20oil%20operator%20$75,000.pdf.
[2119] Paige St. John, "229 Leaks Found in State's Underground Gas Storage Facilities, Most Considered Minor," *Los Angeles Times*, March 24, 2016, sec. California, https://www.latimes.com/local/lanow/la-me-ln-gas-leaks-storage-wells-20160322-story.html.

- March 14, 2016 – Methane and ethane emissions were measured to determine spatial patterns and source attribution of urban methane in the Los Angeles Basin. The surveys demonstrated the prevalence of fugitive methane emissions across the Los Angeles urban landscape and that fossil fuel sources accounted for 58–65 percent of methane emissions.[2120]

- February 25, 2016 – Measurements of methane and other chemicals were taken by aerial equipment following the October gas release from a faulty well in the Aliso Canyon storage field. The data demonstrated that the blowout of this single well created the largest known anthropogenic point source of methane in the United States. The leak lasted 112 days and released a total of 97,100 tons of methane and 7,300 tons of ethane into the atmosphere. This was equal to 24 percent of the methane and 56 percent of the ethane emitted each year from all other sources in the Los Angeles Basin combined.[2121] Aliso Canyon was already a major pollution source before the massive leak.[2122] As determined by the study and reported by major news outlets, the recent methane link is officially the worst in U.S. history.[2123, 2124]

- February 18, 2016 – Stanford and UCLA scientists reported to *Inside Climate News* that the lack of measurement data for the entire 100+ days of community exposures to the Aliso Canyon methane leak, combined with gaps in the science about many of the chemicals, hinders the ability to understand the health impacts of the leak. "'The first week is when we would expect the highest gas concentrations to reach the neighborhood because the pressures in the storage field were the highest,' said Robert Jackson, an earth system science professor at Stanford University who measured methane concentrations in nearby communities during the leak. 'And yet we don't have any information or data for that first week at least.'" Jackson noted that even after monitoring was initiated, it was intermittent rather than continuous.[2125]

- February 18, 2016 – Independent regional experts from USC and UCLA interviewed by Southern California Public Radio expressed skepticism that an industry-funded study ordered by the South Coast Air Quality Management District following the Aliso Canyon methane leak would be rigorously designed to answer specific questions about sub-

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[2120] Francesca M. Hopkins et al., "Spatial Patterns and Source Attribution of Urban Methane in the Los Angeles Basin: Mobile Survey of LA Methane," *Journal of Geophysical Research: Atmospheres* 121, no. 5 (March 16, 2016): 2490–2507, https://doi.org/10.1002/2015JD024429.
[2121] S. Conley et al., "Methane Emissions from the 2015 Aliso Canyon Blowout in Los Angeles, CA," *Science* 351, no. 6279 (2016): 1317–20, https://doi.org/10.1126/science.aaf2348.
[2122] Ingrid Lobet and Mike Reicher, "Aliso Canyon Was Major Pollution Source before Massive Leak," *Inewsource.Org*, February 14, 2016, http://inewsource.org/2016/02/14/aliso-canyon-major-pollution/.
[2123] Nsikan Akpan, "Los Angeles Methane Leak Was Officially the Worst in U.S. History, Study Says," *PBS NewsHour*, February 25, 2016, sec. Science, https://www.pbs.org/newshour/science/los-angeles-methane-leak-is-officially-the-worst-in-u-s-history.
[2124] Amina Khan, "Porter Ranch Leak Declared Largest Methane Leak in U.S. History," *Los Angeles Times*, February 26, 2016, sec. Science, https://www.latimes.com/science/sciencenow/la-sci-sn-porter-ranch-methane-20160225-story.html.
[2125] Phil McKenna, "What Will Be the Health Impact of 100+ Days of Exposure to California's Methane Leak?," *Inside Climate News*, February 18, 2016, https://insideclimatenews.org/news/18022016/health-impacts-aliso-canyon-porter-ranch-methane-leak-california-socal-gas/.

chronic, cumulative exposures, including hydrogen sulfide, which was measured in the nearby Porter Ranch community at levels far greater than the average across American cities.[2126]

- February 13, 2016 – The Los Angeles County Department of Health prepared a *Supplemental Report* for its Expanded Air Monitoring Plan concerning the Southern California Gas Company's Aliso Canyon storage facility long-term gas leak. The report addressed "chemicals of health concern" including toluene, ethylbenzene, xylene, hydrocarbons, VOCs, metals, and radon and concluded, "all results suggest that chemical exposures experienced by residents as a result of the gas leak are below the levels of concern that have been established by various regulatory agencies."[2127] Remaining challenges named by the report itself included possible gaps in data collection, other chemicals present for which no sampling occurred, and further study of the symptoms reported by the public. Many independent scientists did not concur with the Department of Health's ongoing statements that chemical exposures were below levels of concern. Issues raised included monitoring not initiated until a week after the leak began, lack of continuous monitoring, and reliance on "grab samples." Speaking to *Inside Climate News,* John Bosch, a retired air-monitoring expert with more than 30 years' experience at the EPA said, "Grab samples may be OK as a first-tier guestimate of what the problem is, but you really have to have continuous monitoring."[2128]

- February 8, 2016 – PHMSA announced that it might issue its first federal safety regulations for gas storage sites such as Aliso Canyon, while also suggesting site operators voluntarily follow guidelines that the proposed rules (which would likely take years to issue) will likely mirror. According to a report in *Inside Climate News*, these guidelines would not require systems to stop the flow of gas in an emergency or mandate redundancies to prevent methane from leaking into the environment." If PHMSA proceeds to adopt industry guidelines, the resulting rules "may not address two key issues that turned Aliso Canyon into a disaster: emergency shutoff valves and a safer configuration of pipes." Further, even with new regulations, storage units would most likely remain under state jurisdiction, "though state authorities may adopt any new federal rules."[2129] A subsequent story reported on members of Congress pressing PHMSA to create the first federal standards for the 418 underground gas storage facilities for which it has authority to set regulations. In the hearing before a subcommittee of the

[2126] Stephanie O'Neill, "Did the Porter Ranch Gas Leak Cause Long-Term Health Damage?," Archive.kpcc.org, February 18, 2016, https://archive.kpcc.org/news/2016/02/18/57666/did-the-porter-ranch-gas-leak-cause-long-term-heal/.
[2127] Los Angeles County Department of Health, "Aliso Canyon Gas Leak: Results of Air Monitoring and Assessments of Health," February 5, 2016, http://www.publichealth.lacounty.gov/media/docs/AlisoAir.pdf.
[2128] McKenna, "What Will Be the Health Impact of 100+ Days of Exposure to California's Methane Leak?"
[2129] Phil McKenna, "New Federal Gas Storage Regulations Likely to Mimic Industry's Guidelines," *Inside Climate News*, February 8, 2016, https://insideclimatenews.org/news/08022016/federal-gas-storage-regulations-likely-mimic-industry-guidelines-aliso-canyon-phmsa-api/.

House Committee on Transportation and Infrastructure, California representatives "spoke about their efforts to speed up PHMSA's rulemaking for underground gas storage."[2130]

- February 5, 2016 – As part of the Expanded Air Monitoring Plan, Los Angeles County Department of Health provided results for the primary chemicals of concern to assess health effects in residents, pets, and other animals in the community during the Southern California Gas Aliso Canyon storage facility leak. Those chemicals included methane, odorants, and benzene. The maximum level of methane detected was 4,340 ppm and the maximum level of benzene was 30.6 ppb. Early on, average weekly benzene levels that were close to the 1 ppb chronic exposure limit/ health protective level. "Methane levels have remained above normal, but have decreased substantially over time," the report summarized. It also stated that odorants "… remained below instrument detection limits throughout the entire period, including immediately after the leak, even at locations near the leaking well," and that "[b]enzene and other chemicals were originally detectable at levels above normal from within community sampling sites, but peak levels remained below acute exposure thresholds."[2131] While the Los Angeles County Department of Health concluded that "health effects resulting from the on-going leak should be limited to short-term effects resulting from exposure to the odorants," independent scientists, noting data gaps, have challenged these conclusions.

- January 25, 2016 – Some health experts and residents of Porter Ranch, California, adjacent to the Aliso Canyon gas field leak, expressed concern about long-term exposure to the odorous component of the gas, mercaptans, to which regulators attributed several symptoms of residents. Mercaptans are sulfurous chemicals that are added to natural gas to aid in the detection of leaks. Though California regulators have said the health problems, such as headaches, vomiting, and nosebleeds are temporary and will not lead to long-term damage, medical researchers described data gaps to *Inside Climate News.* There is "virtually no research on prolonged exposure to mercaptans." Further, some researchers suggest the health problems may have been caused by different chemicals in the gas, and that "regulators have downplayed the significance of other contaminants that are also present in the leak."[2132]

- January 19, 2016 – Peter Richman, MD, president of the Los Angeles County Medical Association told the *Los Angeles Daily News* that, at nearly three months after the Aliso Canyon methane leak began, physicians had yet to receive a formal statement from the Los Angeles County Department of Public Health about airborne chemical pollutants related to the gas leak or guidelines on how to answer questions from patients about long-term health effects. Richman expressed special concern about prolonged exposure to methane and trace chemicals known to be carcinogenic. Another area physician reported

[2130] Lisa Song, "U.S. Pipeline Agency Pressed to Regulate Underground Gas Storage," *Inside Climate News*, February 26, 2016, https://insideclimatenews.org/news/26022016/phmsa-pipeline-regulator-pressed-regulate-underground-natural-gas-storage-aliso-canyon-methane/.
[2131] Los Angeles County Department of Health, "Aliso Canyon Gas Leak: Results of Air Monitoring and Assessments of Health."
[2132] Lisa Song, "Mercaptans in Methane Leak Make Porter Ranch Residents Sick, and Fearful," *Inside Climate News*, January 25, 2016, https://insideclimatenews.org/news/25012016/porter-ranch-residents-health-effects-methane-leak-aliso-canyon-california/.

that, as of the interview date, his urgent care practice had seen a hundred patients whose symptoms were consistent with exposure to leak-related pollutants.[2133]

- January 14, 2016 – Boston University researcher Nathan Phillips and Bob Ackley of Gas Safety USA drove a high precision GIS-enabled gas analyzer through roads throughout California's San Fernando Valley adjacent to the Aliso Canyon gas leak in early January 2016. Early results showed methane levels elevated 2-67 times the background level.[2134]

- January 13, 2016 – Investigations into the possible cause of the gas leak in Aliso Canyon included the consideration that nearby fracking may have contributed to casing failure. In an email to the *Los Angeles Daily News*, California Department of Conservation Chief Deputy Jason Marshall said that their investigation will examine well records, including those pertaining to "well stimulation operations."[2135] According to a 2015 report prepared for the California Council on Science and Technology, hydraulic fracturing is used about twice yearly to enhance storage "mostly in one facility serving southern California (Aliso Canyon)."[2136]

- January 13, 2016 – "Aliso Canyon is a wake-up call," according to a *Rocky Mountain PBS News* investigative report on the state of U.S. natural gas infrastructure. Natural gas is no longer a cleaner fuel than coal when methane leakage rates exceeds 2-4 percent, but the vast size of the nation's interconnected natural gas storage and pipeline systems makes difficult the task of tallying all the micro-leaks spread across the entire network and answering fundamental questions about exactly how much methane is being lost. The PBS report also expressed concern about the age of many of the system's component parts. According to the piece, nearly half (46 percent) of the nation's transmission pipelines, designed to carry high-pressure gas over long distances, were built in the 50s and 60s and are now more than a half century old.[2137]

- December 30, 2015 – According to the *Los Angeles Daily News,* which unearthed November 2014 state regulatory filing documents, the Southern California Gas Company

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[2133] Susan Abram, "Doctors Treating Porter Ranch Residents Want More Gas-Leak Guidance," *Daily News*, January 19, 2016, https://www.dailynews.com/health/20160119/doctors-treating-porter-ranch-residents-want-more-gas-leak-guidance.

[2134] Dana Bartholomew, "'Plume Chaser' Researchers Fan out across San Fernando Valley to Map Reach of Porter Ranch Gas Leak," *Daily News*, January 14, 2016, https://www.dailynews.com/environment-and-nature/20160114/plume-chaser-researchers-fan-out-across-san-fernando-valley-to-map-reach-of-porter-ranch-gas-leak.

[2135] G. J. Wilcox, "Regulators Probing Whether Fracking Was Connected to Aliso Canyon Gas Well Leak," Daily News, January 14, 2016, https://www.dailynews.com/environment-and-nature/20160113/regulators-probing-whether-fracking-was-connected-to-aliso-canyon-gas-well-leak.

[2136] Jane C. S. Long et al., "An Independent Scientific Assessment of Well Stimulation in California, Volume I: Well Stimulation Technologies and Their Past, Present, and Potential Future Use in California" (California Council on Science and Technology, Lawrence Berkeley National Laboratory, Pacific Institute, 2015), https://ccst.us/publications/2015/2015SB4-v1.pdf.

[2137] J. Wirfs-Brock, "Vast California Methane Leak Is Dire but Not Unique in Aging Infrastructure," *Rocky Mountain PBS News*, January 13, 2016, https://web.archive.org/web/20160120174236/http://inewsnetwork.org/2016/01/13/vast-california-methane-leak-is-dire-but-not-unique-in-aging-infrastructure/.

knew about the corrosion and potential for leakage at Aliso Canyon prior to the massive blow-out. "In written testimony to the California Public Utilities Commission, [SoCalGas Director of Storage Operations Phillip] Baker described a reactive maintenance process that hinted at major leakage problems underground."[2138]

- November 20, 2015 – California state agencies collaborated with Aviation Scientific to measure methane emission rates at two early November dates, finding rates of 44,000±5,000 kilograms of methane per hour and 50,000±16,000 kilograms of methane per hour. The results indicated that the Aliso Canyon gas leak would have contributed about a quarter of California's methane emissions for the time period studied.[2139]

- November 20, 2015 – According to the *Los Angeles Times*, one month into the Aliso Canyon ongoing gas leak, Southern California Gas warned that it "might need several months" to plug the leak. An order from California's Division of Oil, Gas and Geothermal Resources, "stated that an 'uncontrolled flow of fluids' and gas was escaping and the operator had failed to fully inform state officials about the well's status. Steve Bohlen, the state oil and gas supervisor, also directed the company to submit a schedule for remediation work or for drilling a relief well."[2140]

- October 19, 2015 – *Houston Public Media* reported on the 125 caverns carved out of salt storing natural gas liquids (NGLs), thousands of feet under the city of Mont Belvieu, Texas, east of Houston. "There have been fiery accidents here. But nothing like what happened 23 years ago at a different [NGL] storage site 100 miles to the west. 'A bomb-like blast literally blew residents in this small community out of their beds this morning, said a reporter for Dallas's Channel 8 as he did a live report just outside the city of Brenham." That blast, which killed three and injured 21, was reportedly caused by the lack of an emergency shut-off valve. There are no federal standards in place for such requirements. Twenty-three years later, a month prior to the *Houston Public Media* report, "at a hearing held by the U.S. Senate Committee on Commerce, Science, & Transportation, Donald Santa, head of the Interstate Natural Gas Association of America, told the senators that it was only in recent weeks that the industry approved standards for storing natural gas." Texas did enact legislation a year after the deadly blast "and now requires emergency shutoff valves and inspections for leaks every five years."[2141]

[2138] Mike Reicher, "SoCalGas Knew of Corrosion at Porter Ranch Gas Facility, Doc Shows," *Daily News*, December 31, 2015, https://www.dailynews.com/general-news/20151230/socalgas-knew-of-corrosion-at-porter-ranch-gas-facility-doc-shows.
[2139] California Air Resources Board, "Report on Greenhouse Gas Emissions from Aliso Canyon Leak," *Los Angeles Times*, November 20, 2015, http://documents.latimes.com/report-greenhouse-gas-emissions-aliso-canyon-leak/.
[2140] T. Barboza, "Natural Gas Leak That's Sickening Valley Residents Could Take Months to Fix," *Los Angeles Times*, November 21, 2015, sec. California, https://www.latimes.com/local/california/la-me-1121-gas-leak-20151121-story.html.
[2141] Dave Fehling, "On Edge Of Houston, Underground Caverns Store Huge Quantities Of Natural Gas Liquids," *Houston Public Media*, sec. Energy & Environment, accessed September 22, 2021, https://www.houstonpublicmedia.org/articles/news/2015/10/19/124674/on-edge-of-houston-underground-caverns-store-huge-quantities-of-natural-gas-liquids/.

- October 5, 2011 – The federal district court in Topeka struck down Kansas gas-safety laws in 2010, and 11 underground storage sites with a capacity of more than 270 billion cubic feet of gas have gone uninspected, leaving thousands of Kansans to live on and around uninspected gas-storage fields.[2142]

- 2008 – When considering the possibility of storing natural gas in a variety of underground gas storage facilities, the UK government commissioned the British Geological Survey to identify the main types of facilities currently in operation worldwide along with any documented or reported failures and incidents which have led to release of stored product. The researchers found that California had the most incidents, but concluded that many of these problems and geological factors would not necessarily be applicable to the UK. The incidents most relevant to gas storage in the UK resulted from a failure of either the man-made infrastructure (well casings, cement, pipes, valves, flanges, compressors etc.), or human error, which has included overfilling of caverns and inadvertent intrusion. Extreme natural events, including earthquakes, also played a role. The researchers looked closely at incidents in salt caverns that had been repurposed to store gas. They reported that "early salt cavern storage in the US was done in brine wells that had been solution mined [in which salt deposits are melted away with hot water or steam] without consideration for subsequent storage in the depleted caverns. This practice sometimes resulted in later problems for storage operations in retrofitted brine caverns." The authors conclude that the rate for a geological failure of the storage cavity in an underground gas storage facility is of the order of 10^{-5} failures per well year.[2143]

Liquefied natural gas (LNG) facilities

Liquefied natural gas (LNG) is methane vapor that has been turned into liquid through a cryogenic process that lowers the temperature of the gas to its condensation point (-259° F). Chilling natural gas to its liquid state shrinks its volume by a factor of 600, allowing LNG to be transported to places where pipelines don't reach, as when it is exported overseas on massive tanker ships. LNG is also sometimes used as vehicle fuel in, for example, long-haul trucks. LNG facilities encourage fracking by creating storage for the glut of gas that fracking has created, by enabling its export, and by driving up prices and profit margins. LNG facilities are capital-intensive and consist of liquefaction plants, import/export terminals, tanker ships, regasification terminals, and inland storage equipment.

Increased reliance on LNG poses risks of violating internationally agreed upon climate targets. LNG liquefaction requires immense energy in order to achieve the ultra-low temperatures required for condensation. An LNG facility typically requires its own power plant. Because they rely on evaporative cooling, LNG tanks are leaky by design: to maintain the liquid at super-

[2142] Dion Lefler, "Lawsuit Leaves Large Gas Storage Fields in Kansas Unregulated," *The Wichita Eagle*, October 5, 2011, https://www.kansas.com/news/article1071558.html.
[2143] Deborah Keeley, "Failure Rates for Underground Gas Storage: Significance for Land Use Planning Assessments," Research Report (Health and Safety Laboratory, 2008), https://www.hse.gov.uk/research/rrpdf/rr671.pdf.

chilled temperatures and prevent explosions, vaporized methane is vented from storage tanks directly into the atmosphere. Larger tanks are engineered to capture boiled-off gas, but this process is not leak-proof. Before it is combusted or sent down a pipeline, LNG must be regasified via an energy-intensive process that requires massive infrastructure of its own, including periodic flaring to control pressure. Refrigeration, venting, leaks, flaring, and shipping make LNG more energy intensive than conventional natural gas. A recent analysis shows that exporting large quantities of LNG from the United States will likely cause global greenhouse gas emissions to rise not only because of its energy penalty but also because LNG exports add more fossil fuels to the global market and extend the lifespan of U.S. coal-fired plants.

LNG creates acute public safety risks. LNG explodes when spilled into water and, if spilled on the ground, can turn into rapidly expanding, odorless clouds that can flash-freeze human flesh and asphyxiate by displacing oxygen. If ignited at the source, LNG vapors can become flaming "pool fires" that burn hotter than other fuels and cannot be extinguished. LNG fires burn hot enough to cause second-degree burns on exposed skin up to a mile away. LNG facilities pose significant risks to nearby population centers and have been identified as potential terrorist targets. In June 2022, a vapor cloud explosion and fire at the Freeport LNG facility in Texas closed the facility for eight months. No one inside the plant was injured, but lifeguards at a nearby beach were thrown from their chairs by the blast.

LNG plants create public health risks for nearby communities from toxic air pollutants including carbon monoxide, nitrogen oxides, sulfur dioxide, and volatile organic compounds.

- May 17, 2023 – A policy analysis of European energy security by the German think tank Dezernat Zukunft finds that increased reliance on LNG imports poses risks of violating climate targets, especially if Europe finances more new export facilities abroad that have no chance of becoming operational until after 2027. While European import terminals can function to provide energy security for crisis times, "in the long term, only phasing out natural gas by transitioning to efficient renewable energy systems ultimately reconciles energy and climate security."[2144]

- February 6, 2023 – Investigative reporting on air pollution from LNG export terminals found that LNG facilities are underreporting and miscalculating the amount of toxic air emissions from their facilities. These pollutants include carbon monoxide, nitrogen oxides, sulfur dioxide and volatile organic compounds, sometimes exceeding the facilities' permitted limit.[2145]

- November 16, 2022 – A report issued by the Pipeline and Hazardous Materials Safety Commission found that procedural errors and employee fatigue caused by understaffing

[2144] Felix Heilmann et al., "LNG, Climate and Energy Security: Towards a Comprehensive Approach for Europe" (Dezernat Zukunft, May 17, 2023), https://www.dezernatzukunft.org/lng-climate-and-energy-security-towards-a-comprehensive-approach-for-europe/.
[2145] Terry L. Jones, "LNG Export Terminals Pose a Growing and Invisible Threat: Air Pollution," *Louisiana Illuminator*, February 6, 2023, https://lailluminator.com/2023/02/06/lng-export-terminals-pose-a-growing-and-invisible-threat-air-pollution/.

contributed to the June 2022 vapor cloud explosion at the Freeport LNG facility in Quintana, Texas, 70 miles south of Houston.[2146]

- July 2, 2021 – Calling its own project "impractical," Pieridae Energy said it will not proceed with its planned LNG processing and export facility in Nova Scotia with an estimated construction cost of $14 billion. Although the German government had offered the company a US $4.5 billion loan guarantee contingent on its ability to secure additional financing, the company failed to submit an application for for additional funds from the Canadian government by the agreed-upon deadline. The editor and publisher of the *Halifax Examiner* noted that the company could still alter the project—importing natural gas from Pennsylvania through existing pipelines rather than as originally planned from Alberta—but such a shift would create a dependency on the problem-plagued Enbridge compressor station in Weymouth, Massachusetts, throwing the viability of the project into doubt. "Natural gas's time has passed. The public hates it, governments won't finance it, and no one is buying."[2147]

- June 30, 2021 – Pieridae Energy, having missed a deadline to submit an application to the Canadian government for $925 million in grant, repayable contribution, or loan guarantee for its planned LNG facility in Nova Scotia, would still need to undergo environmental assessment and receive regulatory permissions even if all the necessary funding were secured. The plan's opponents are prepared to mount substantive challenges, out of concern that the LNG facility would prevent Nova Scotia from meeting emissions goals, that the large labor camp would threaten the safety of native Canadian women, and that the use of public funds to increase fossil fuel production in a time of accelerating renewable energy investments is inappropriate.[2148]

- June 22, 2021 – U.S. company New Fortress Energy (NFE) announced its intention to apply for permission for an LNG terminal in Ireland despite the country's May 2021 pause on all new LNG terminals. The project would include a power plant and battery storage facility, with an offshore LNG terminal in the Shannon estuary. A previous plan was put on hold in 2019 because of concerns over the import of fracked gas. Ireland has pledged to obtain 70 percent of energy from renewables by 2030 and has excluded the use of fracked gas. NFE claims that its project will not be dependent on fracked gas.[2149]

- June 16, 2021 – As part of the Further Consolidated Appropriations Act of 2020, PHMSA entered into an agreement with the Transportation Research Board, a major program of the National Academies of Sciences, Engineering, and Medicine (NASEM) to convene a committee of independent experts to critique the safety research and testing

[2146] IFO Group, "June 8, 2022 - Loss of Primary Containment Incident Investigation Report," October 30, 2022, 2, https://subscriber.politicopro.com/eenews/f/eenews/?id=00000184-7d8d-d7f7-a79c-ff8f6e230001.
[2147] Tim Bousquet, "The Goldboro LNG Plant Scheme Has Collapsed," *Halifax Examiner*, July 2, 2021, https://www.halifaxexaminer.ca/featured/the-goldboro-lng-plant-scheme-has-collapsed/.
[2148] Rose Murphy, "Feds Haven't Received Funding Application for Goldboro LNG Project, Says MP," CBC.Ca, June 30, 2021, https://www.cbc.ca/news/canada/nova-scotia/lng-pipeline-goldboro-nova-scotia-1.6085957.
[2149] Sarah Collins, "US Backer Revives Its Plans for €650m Shannon LNG Project," June 22, 2021, https://www.independent.ie/business/irish/us-backer-revives-its-plans-for-650m-shannon-lng-project-40567970.html.

protocols undertaken by the task force engaged in the final rulemaking process for allowing the transportation of LNG by rail tank car. Among other concerns, the committee in its report asked for a clearer rationale for how full-scale impact testing, tank fire testing, and worst-case scenarios protocols were developed. The second phase of the project, to be completed in mid-2022, will provide a more in-depth review and examination of the applicability of existing guidelines for emergency responses to LNG rail incidents, including "incidents caused by deliberate acts, human factors, or track component defects."[2150]

- June 3, 2021 – According to an engineering analysis, the force of a vapor cloud explosion (VCE) at LNG plants has likely been significantly and systematically underestimated by industry. VCEs occur when heavier hydrocarbons, which are used to cool natural gas, leak and ignite. LNG terminals, which typically hold 50 tons of these refrigerants, are usually designed with barriers at the perimeter to prevent vapor leaks from spreading off site, but, on rare occasions, as during windless conditions, such barriers can allow vapor accumulation sufficient for explosions, which can be massive. In 2019, for example, a VCE in Philadelphia threw a 38,000-pound vessel across the Schuylkill River and led to the permanent closure of that oil refinery. Although federal standards are in place for risk calculations for other types of hazards, PHMSA had accepted industry's computer model indicating that the force of a VCE would be greatly diminished by the time it reached the edge of the facility. However, an expert study not associated with the industry showed that the force of that type of incident could be 15 to 20 times higher than projections from industry modeling. PMHSA intends to develop new rules on VCEs in the coming year and yet, meanwhile, approved safety plans for three proposed LNG terminals in Louisiana (although one of three was subsequently canceled because of financial issues). Jerry Havens, the former director of the Chemical Hazards Research Center at the University of Arkansas said, "If something doesn't get corrected, there might be some terrible accidents."[2151]

- May 14, 2021 – The Irish government pledged in June 2020 to disallow the import of LNG derived from fracked gas, and Ireland's Department of the Environment, Climate and Communications (DECC) has said that no LNG projects should proceed until a review of the country's energy supply security is completed. DECC has also said that Ireland would withhold EU member state approval for EU funding for LNG import terminals in the country. A spokesperson for the agency commented, "as Ireland moves toward climate neutrality, it does not make sense to develop LNG projects importing fracked gas." This policy has led to the suspension of one planned project by a U.S. developer, but two others are still in progress: Shannon and Predator. The High Court in Ireland ruled against all development consents for the Shannon LNG project, but Shannon is preparing new applications and hopes to come online in late 2022. Predator, a

[2150] Policy Studies, Transportation Research Board, and National Academies of Sciences, Engineering, and Medicine, *Preparing for LNG by Rail Tank Car: A Review of a U.S. DOT Safety Research, Testing, and Analysis Initiative* (Washington, D.C.: Transportation Research Board, 2021), https://doi.org/10.17226/26221.
[2151] Will Englund, "Engineers Raise Alarms Over the Risk of Major Explosions at LNG Plants," *The Washington Post*, May 3, 2021, https://www.washingtonpost.com/business/2021/06/03/lng-export-explosion-vce/.

UK project, plans a floating LNG import terminal and stated it would not use LNG sourced from fracking.[2152]

- April 30, 2021 – Plans for a €40 million LNG terminal at the port of Bratislava, Slovakia are backed by unsubstantiated claims from the state-owned investor that the facility will reduce pollution and greenhouse gas emissions on the Danube and make freight transport "greener." Part of an EU plan to build a Rhine-Danube transport corridor connecting different means of transport across Europe, the terminal will be located less than one kilometer away from a densely populated area, and, according to critics, would increase traffic and cause a reduction in air quality. Concerns about the project's potential to increase Slovakia's reliance on natural gas have prompted request for an analysis of its compatibility with EU climate policies.[2153]

- April 26, 2021 – The United Kingdom approved $1 billion for a large LNG development in Mozambique that is now facing a court challenge on the grounds that the project is consistent with neither the United Kingdom's nor Mozambique's obligations under the Paris Climate Agreement. The construction phase of the project would increase Mozambique's GHG emissions by up to 10 percent and the burning of the fuel produced would cause emissions equivalent to those of the EU's total aviation sector.[2154]

- April 22, 2021 – Plans for three LNG import terminals in Germany have received strong state support, even though plans for a renewable energy transition would render over 70 percent of all gas distribution grids in that nation unnecessary. A research team examined the ways in which the continuing build-out of LNG infrastructure in Germany locks in a dependency on natural gas, allowing the industry to avoid stranded assets while also impeding the transition to renewables and substantially delaying the attainment of climate goals. They found that local and political forces work together to create momentum for LNG proposals and to keep federal opposition weak. The continued use of gas requires no change in equipment or consumer behavior while political pressure from the United States to reduce Russian gas imports and to import U.S. LNG keep climate and environment issues subordinate to short-term economic and energy security concerns. The authors recommend that policy and energy investment decisions include climate targets and the risks of locking in natural gas dependencies.[2155]

- April 15, 2021 – The Delaware River Basin Commission (DRBC), comprised of representatives of New York, New Jersey, Pennsylvania, and Delaware, as well as the commander of the U.S. Army Corp of Engineers' North Atlantic Division, has made

[2152] Stuart Elliot, "Ireland Advises Against All LNG Project Developments During Energy Review," S&P Global, May 14, 2021, https://www.spglobal.com/platts/en/market-insights/latest-news/natural-gas/051421-ireland-advises-against-all-lng-project-developments-during-energy-review.
[2153] Irena Jenčová, "Bratislava Port to Get Its Own €40 Million LNG Terminal," Euractiv.com, April 30, 2021, https://www.euractiv.com/section/politics/short_news/bratislava-port-to-get-its-own-e40-million-lng-terminal/.
[2154] Brendan Montague, "Britain's $1 Billion Bet Against the Climate," *Ecologist*, April 26, 2021, https://theecologist.org/2021/apr/26/britains-1billion-bet-against-climate.
[2155] Hanna Brauers, Isabell Braunger, and Jessica Jewell, "Liquefied Natural Gas Expansion Plans in Germany: The Risk of Gas Lock-In under Energy Transitions," *Energy Research & Social Science* 76 (2021), https://doi.org/10.1016/j.erss.2021.102059.

paradoxical decisions regarding fracked gas. In February 2021 the DRBC banned fracking in the area that it oversees. However, only a few months earlier, the Commission approved a dock in Gibbstown, New Jersey to export LNG from a plant in Pennsylvania, potentially placing at risk over 1.5 million people in an area ranging over 200 miles from the plant to the export dock. The Pennsylvania Department of Environmental Protection estimated that the LNG plant would produce more than one million metric tons of greenhouse gases yearly and burning the gas after delivery would produce millions more. A special permit from the Trump administration for the use of rail to transport LNG from Pennsylvania to New Jersey for this project was followed by a complete lifting of the federal ban on LNG transport by rail in densely populated areas in 2020. When New Fortress Energy built a dock in Gibbstown in 2017, the company indicated the facility would not use it for LNG export. However, a subsidiary of New Fortress applied for a permit to build the Pennsylvania LNG plant intending to export the gas from a port on the Delaware River. The subsidiary, Delaware River Partners, subsequently applied for a permit to construct another dock attached to the Gibbstown facility, which would be used for LNG export. Not only adjacent to a low-income and largely non-white "overburdened community," the location itself is a Superfund site, and dredging needed for the dock could release carcinogenic PCBs into the river. When the DRBC approved "Dock 2," the agency stated that the climate and environmental issues would need to be addressed at the state, interstate, and federal level. New Fortress still needed permits from New Jersey's Department of Environmental Protection and an export permit from the federal Department of Energy. A motion for summary judgement was filed with the New Jersey district court asking that the Army Corps of Engineers' permit be nullified because a full environmental impact assessment had not been done prior to approval. Other roadblocks to the project include the possibility that President Biden could revoke the prior administration's executive order regarding LNG rail transport.[2156]

- March 30, 2021 – Bowing to public pressure and determining that its chemical discharges would harm local wetlands, the Australian government denied the LNG import terminal at Crib Point planned by AGL Energy. Australia's biggest climate polluter, AGL Energy had already spent about $130 million on the project. AGL also plans to split its business in two, in an attempt to improve its emissions profile and reputation, by separating out its continued coal-fired power generation.[2157]

- January 22, 2021 – The accidental release of LNG from a railroad tank car can result in fire and boiling liquid expanding vapor explosions. Because of these risks, transport of LNG by rail, which is regulated by the PHMSA and the Federal Railroad Administration, had been allowed only on a case-by-case basis. However, on July 24, 2020, PHMSA finalized the LNG by rail regulation allowing the practice. The decision has been

[2156] Zoya Teirstein, "The Delaware River Basin Paradox: Why Fracking Is So Hard to Quit," *Grist*, April 15, 2021, https://grist.org/politics/the-delaware-river-basin-paradox-why-fracking-is-so-hard-to-quit/.
[2157] Australian Associated Press, "Victoria Blocks AGL's Gas Terminal on Environmental Grounds," *The Guardian*, March 30, 2021, https://www.theguardian.com/business/2021/mar/30/victoria-blocks-agl-energy-gas-terminal-crib-point-split-business.

challenged in court, but the Biden administration requested that the case be delayed until it reviews the LNG by rail rule.[2158]

- November 9, 2020 – LNG transport from Russia to Asia via the Northeast Passage has markedly increased due to climate change-induced ice melt. That sea route, from Russia past the North Pole and Alaska and south to China, historically was covered with ice for most of the year, but, when available for shipping, cuts about 2400 nautical miles off the trip. The route is now open for much longer periods each year, and there have been thousands of transits since 2015. China, expected to double its natural gas use in the next 15 years, had previously obtained most of its natural gas via pipelines from other Asian countries and southern Russia. In 2017, Russia opened an LNG export terminal on the Yamal Peninsula that offers easy access, via the Northeast Passage, to China. Traffic is expected to increase as ice melt continues. In contrast, a proposed US LNG export terminal in Oregon is on hold because of climate concerns.[2159]

- July 6, 2020 – Investors concerned about falling demand, rising competition from renewable energy, and opposition due to climate concerns have delayed financing for at least 20 of 45 major LNG projects in preconstruction development around the world.[2160] "Investing in new fossil fuel infrastructure like liquefied natural gas (LNG) terminals is increasingly an economically unsound decision," commented Andrew McDowell, the vice president of European Investment Bank (EIB). EIB will stop financing fossil fuel projects after 2021. The pandemic has also slowed LNG terminal development. The industry and some nations, however, still plan to boost LNG exports over the next 10 years. Methane, the main component of LNG, is a potent greenhouse gas, and these plans raise concerns about the possibilities of achieving the goals of the Paris climate accord.

- June 23, 2020 – The US Energy Information Administration reported that LNG export capacity would be used at less than 50 percent during June, July, and August 2020.[2161] Seventy-four US cargoes were exported in January 2020, but over 70 were canceled for June and July and more than 40 canceled for August. According to the report, "A mild winter and COVID-19 mitigation efforts have led to declining global natural gas demand and high natural gas storage inventories in Europe and Asia, reducing the need for LNG imports. Historically low natural gas and LNG spot prices in Europe and Asia have affected the economic viability of U.S. LNG exports."

- June 23, 2020 – Royal Dutch Shell's "Prelude," a floating plant designed to produce LNG from remote offshore gas fields has not been operational since January 2020

[2158] Environmental & Energy Law Program, "LNG by Rail Rule," Regulatory Tracker (Harvard Law School, January 22, 2021), https://eelp.law.harvard.edu/2021/01/lng-by-rail-rule/.
[2159] Tim McDonnell, "A Brutal New Climate Feedback Loop Is Brewing in the Arctic," *Quartz*, November 9, 2020, https://qz.com/1928866/how-the-northeast-passage-is-helping-russia-sell-more-natural-gas/.
[2160] Matthew Green, "Global LNG Projects Jeopardized by Climate Concerns, Pandemic Delays - Report," *Reuters*, July 6, 2020, sec. Environment, https://www.reuters.com/article/us-climate-change-gas-idUKKBN247303.
[2161] U.S. Energy Information Administration, "U.S. Liquefied Natural Gas Exports Have Declined by More than Half so Far in 2020 - Today in Energy - U.S. Energy Information Administration (EIA)," June 23, 2020, https://www.eia.gov/todayinenergy/detail.php?id=44196.

because of safety problems, reported *Forbes*.[2162] Shell had not revealed the cost of the project, but estimates ranged from $12 billion to $17 billion. Operational costs were estimated to be high as well. Analysts at Goldman Sachs estimated that Prelude's costs are more than double those from other new LNG projects. Oil and gas prices have fallen dramatically since the project began about 10 years ago, and an analyst at Credit Suisse said that record low LNG prices make it difficult to cover operating costs. In contrast, Shell Australia's chairman said that Shell was pleased with Prelude's progress.

- June 19, 2020 – Following President Trump's executive order signed in Houston in April 2019 to reconsider the prohibition of LNG transport by rail, the U.S. Department of Transportation (USDOT) and the Pipeline and Hazardous Material Safety Administration (PHMSA) issued a final rule in June 2020 allowing the practice.[2163] The Congressional Research Service (CRS) published a report addressing the new rule, including criticism: "perceived public safety and security risks of LNG by rail have raised concerns among state officials, the National Transportation Safety Board, and other members of Congress."[2164] The rule includes new operational safeguards and monitoring requirements for the highly combustible product including increased outer tank thickness, new braking requirements, and remote monitoring of pressure and location of each LNG car. There are also requirements that attempt to reduce security risk. The CRS report reviewed the inherent risks of LNG by rail, safety and environmental record of the industries, and policy issues including legislation actions. Ongoing concerns included inadequacy of emergency responder training, manpower, and resources to deal with an LNG rail accident. LNG burns hotter and more rapidly than gas or oil. If LNG spills but does not ignite it can cause asphyxiation or can create a vapor cloud which can burn if it contacts an ignition source. A boiling liquid expanding vapor explosion (BLEVE) could occur if a tank car was heated until rupture, resulting in a blast wave. "Cascading failures," where an LNG release and fire from one tank car can trigger succeeding cars to fail in the same manner, have occurred in rail accidents involving rail shipments of crude oil and ethanol, according to the report. Proposed legislation includes an Act to carry out further evaluation of LNG-by-rail safety, containing specific requirements, and which "would rescind any special permit or approval for the LNG transportation by rail tank car issued prior to enactment and would prohibit any regulation, special permit, or approval prior to the conclusion of a specified study period."

- May 25, 2020 – Seven LNG projects are in various stages of construction in Canada's British Columbia, where the province is expecting a fracking boom to feed the projects

[2162] Tim Treadgold, "Shell's $12 Billion LNG Experiment Becomes A Big Headache," *Forbes*, June 23, 2020, sec. Asia, https://www.forbes.com/sites/timtreadgold/2020/06/23/shells-12-billion-lng-experiment-becomes-a-big-headache/.
[2163] U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration, "U.S. Department of Transportation Issues Final Rule for the Safe Transportation of Liquefied Natural Gas by Rail Tank Car | PHMSA," Press Release, June 19, 2020, https://www.phmsa.dot.gov/news/us-department-transportation-issues-final-rule-safe-transportation-liquefied-natural-gas-rail.
[2164] P. W. Parfomak and J. Frittelli, "Rail Transportation of Liquefied Natural Gas: Safety and Regulation" (Congressional Research Service, 2020).

while concomitantly trying to address methane emissions.[2165] The largest of the LNG projects under construction is expected to require double the existing fracking operations. The province must also consider significant emissions from inactive and orphan wells. As new wells are drilled to meet LNG demands, the number of unattended wells is expected to rise dramatically, which will undermine efforts to cut methane emissions. British Columbia's goal is a 45 percent reduction in methane emissions from 2014 levels, to be achieved by 2025. Controversy surrounds the province's methods of assessing methane emissions, with one evaluation indicating that emissions were 2.5 times the province's official report. British Columbia has formed a methane research group to better evaluate the problem, but, the "group's work is focused solely on upstream operations—companies that extract or produce oil and gas—meaning facilities like LNG Canada are off the hook as an end-use, downstream facility." One member of the group noted that LNG Canada receives significant government subsidies including carbon tax exemptions estimated in excess of $150 million a year: "If the government wants to reach its methane target it needs to stop subsidizing oil and gas."

- May 15, 2020 – Now recognized by the European Union (EU), the problem of high methane emissions from the oil and gas industry offsets any potential climate benefits of importing LNG over coal. The EU's goal of climate neutrality by 2050 and multi-pronged strategies to curb methane emissions of imported natural gas, considers measurement and reporting across fossil fuel sectors and supply chains, as reported by the Germany-based, cross-border focused energy journalism group, *Clean Energy Wire*.[2166] Such a strategy, codified as concrete legislation, could force U.S. LNG producers to take their methane leakage problem more seriously if they want continued access to EU markets. The United States has been a net exporter of LNG since 2016, with most of the gas coming from the Permian Basin in western Texas and southeastern New Mexico that is now the world's largest oil-producing region and the United States' second biggest gas-producing region. Recent studies have shown that flaring, venting, and leaking of natural gas are much worse in the Permian Basin than elsewhere in the United States. One recent study indicated that the amount of fugitive methane emissions from the Permian oil and gas operations nearly triples the climate impact of burning the produced gas. Natural gas production, liquefaction, and transport are all energy intensive and lead to carbon dioxide emissions as well.

- March 1, 2020 – In April 2019 Donald Trump signed an executive order instructing the US Department of Transportation to write rules allowing rail transport of LNG. A detailed piece in the National Fire Protection Association's *NFPA Journal* detailed the issues of concern to the safety community, in the period between the Trump order and the release of the final rule.[2167] Public safety organizations such as the International

[2165] Natalia Balcerzak, "'I Don't Think We Will Ever Catch up': B.C. Methane Targets out of Reach amid Growing LNG, Fracking," *The Narwhal*, May 25, 2020, https://thenarwhal.ca/climate-change-b-c-methane-targets-out-of-reach-growing-lng-fracking/.
[2166] Julian Wettengel, "Unravelling the Climate Footprint of U.S. Liquefied Natural Gas," *Clean Energy Wire*, May 15, 2020, https://www.cleanenergywire.org/news/unravelling-climate-footprint-us-liquefied-natural-gas.
[2167] Jesse Roman, "NFPA Journal - LNG By Rail, March/April 2020," *NFPA Journal*, April 2020, https://www.nfpa.org/News-and-Research/Publications-and-media/NFPA-Journal/2020/March-April-2020/Features/LNG-Trains.

Association of Firefighters (IAFF), the National Association of Fire Marshalls, and the National Transportation Safety Board (NTSB) were "strongly opposed" to the proposed rule. "The IAFF, pointing out that LNG will quickly evaporate into an immense and potentially flammable vapor cloud when exposed to ambient air, wrote that 'it is nearly certain any accident involving a train consisting of multiple rail cars loaded with LNG will place vast numbers of the public at risk while fully depleting all local emergency response forces.'" Safety experts noted that communities and public agencies should be preparing for rail accidents and recommended the involvement of the nation's 3,000 local emergency planning committees, mandated by Congress in 1986 to develop comprehensive emergency response plans.

- January 28, 2020 – For use as a marine fuel, there was no climate benefit for 20-year global warming potential from using LNG, and the use of LNG appeared to actually worsen the climate impact of shipping, according to a working paper from the International Council on Clean Transportation.[2168] More ships are being built to use LNG, which emits 25 percent less CO_2 than usual fuel for the same amount of propulsion. The study evaluated climate impact by comparing lifecycle greenhouse gas emissions of LNG, marine gas oil, very low sulfur fuel, and heavy fuel oil when used for marine shipping. The assessment included leakage during extraction, processing, and transport, as well as downstream emissions from combustion and unburned gas. The paper emphasized that the International Maritime Organization has developed climate goals, has "signaled" that it will regulate emissions, and that "continued investment in LNG infrastructure on ships and on shore risks making it harder to transition to zero-emission vessels in the future."

- January 14, 2020 – The NTSB warned of the risk of "catastrophic" fires and explosions in response to a Trump administration draft rule to allow LNG transport by rail. Other groups, including fire marshals, the union representing rail engineers, and 16 state attorneys general, also oppose the rule. The NTSB recommended that PHMSA should require stricter safety precautions, but some rail industry groups oppose this. The executive director of the National Association of State Fire Marshals said, "The combination of a lack of information with no increased safety measures…puts the public and our first responders at even greater risk."[2169]

- January 11, 2020 – Scientists from Greece's National Centre of Scientific Research identified "scientific and harmonization gaps" at ports storing and transferring LNG.[2170] The study examined 35 legislative documents and 23 articles in an extensive review of literature regarding safety and risk assessment, and summarized regulations addressing LNG storage tanks, bunker trucks, buffer ships, and LNG fueled ships. At the time of the

[2168] Nikita Pavlenko et al., "The Climate Implications of Using LNG as a Marine Fuel | International Council on Clean Transportation," Working Paper (The International Council on Clean Transportation, January 28, 2020), https://theicct.org/publications/climate-impacts-LNG-marine-fuel-2020.
[2169] Mike Lee, "Feds Warn of 'Catastrophic' Blasts from Trump LNG Rule," *E&E News*, January 14, 2020, https://web.archive.org/web/20200114194145/https://www.eenews.net/energywire/stories/1062074737.
[2170] Olga Aneziris, Ioanna Koromila, and Zoe Nivolianitou, "A Systematic Literature Review on LNG Safety at Ports," *Safety Science* 124 (2020): 104595, https://doi.org/10.1016/j.ssci.2019.104595.

study, there were 21 operating LNG ports worldwide, and ten more with "confirmed plans to operate by 2020," but, the authors stated, "the knowledge regarding safe storage, handling and supply of LNG is still insufficient." They identified gaps including harmonization of LNG safety regulations at sea and on land, for all LNG operations at ports and within various countries. Additionally, more work needs to be done using quantitative risk methods to better define safety and hazardous zones during LNG storage and bunkering at ports. The authors identified areas for further work by the academic community and industry organizations.

- October 10, 2019 – Authors of an overview of risk analysis in the LNG sector proposed a "comprehensive classification framework," a classification strategy for LNG risk studies covering "more aspects of risk analysis process compared with the existing review articles."[2171] The storage, transport, and use of LNG carries the potential for catastrophic accident, and the field of risk analysis has been used "to identify the potential hazards, calculate the probability of accidents, as well as assessing the severity of consequences." The authors reviewed and categorized 66 papers addressing risk analysis in the LNG sector. The literature was examined with regard to methods, tools, data sources, and the type of LNG facility. The various risk analysis tools were described, along with their advantages and drawbacks. Authors said that in spite of progress in the application of LNG risk analysis in the LNG sector, further research is needed, for which they make specific recommendations. These included attention to improved data quality and the introduction of real-life electronic data, more use of dynamic versus conventional risk assessment, and the use of more powerful risk assessment tools and methods. The review of data sources revealed that "expert judgement" was the most common source, suggesting that there is a lack of good quality data for LNG risk analysis.

- September 5, 2019 – The Trump Administration has used multiple means to push Europe to buy more American LNG, according to the *Houston Chronicle*.[2172] Trump aggressively promoted the exports through speeches and meetings with heads of state, and eight federal agencies have been charged with getting overseas gas infrastructure built. US officials have acted as "go-betweens" with foreign counterparts regarding their own energy sectors, assisting US allies in developing their own gas exports. Some in Europe, however, question America's sincerity about the stated goal of helping them achieve energy security: "After the Senate passed sanctions in 2017 targeting Russia's Nord Stream 2 natural gas pipeline into Germany—a project the Trump administration has fought to block—Austria and Germany's foreign officials released a joint statement calling the vote a bid to aid American energy companies."

- July 22, 2019 – An upcoming rule from PHMSA is expected to concern "streamlining U.S. regulations and harmonizing them with those in other countries," rather than

[2171] Isaac Animah and Mahmood Shafiee, "Application of Risk Analysis in the Liquefied Natural Gas (LNG) Sector: An Overview," *Journal of Loss Prevention in the Process Industries* 63 (January 2020): 103980, https://doi.org/10.1016/j.jlp.2019.103980.
[2172] James Osborne, "Trump's Hard Sell of American LNG," *Houston Chronicle*, September 5, 2019, sec. Energy, https://www.houstonchronicle.com/business/energy/article/Trump-s-hard-sell-of-American-LNG-14414269.php.

focusing on safety and prevention of catastrophic explosions, reported *E&E News*.[2173] A PHMSA working group indicated in September 2018 that there "… is no process in place to evaluate the suitability of the software models to calculate these hazards." Five new LNG export facilities were expected to be operational by the end of 2019, and six more had been fully permitted. It remained unclear what the PHMSA will do to address the risk of explosion. Jerry Havens, a professor emeritus of chemical engineering, expressed concern that the current LNG infrastructure fails to account for the risk of catastrophe. Current LNG computational safety models are proprietary so he could not determine their accuracy, and PHMSA had no protocol to evaluate the models. Havens said that the current system might dramatically underestimate the power of a worst-case accident by a factor of ten.

- July 1, 2019 – The climate impact of proposed LNG expansion would be twice that of the current base of coal in the United States, Global Energy Monitor told *CNN*, for their coverage of a new report by the network of researchers who track fossil fuel projects.[2174] This impact is primarily related to leaks of methane, the potent greenhouse gas, and the reason that the United Nations' Intergovernmental Panel on Climate Change has called for reducing natural gas in the coming decades, *CNN* reported. Economic viability is also in doubt, according to the Global Energy Monitor report, with "plunging renewable energy costs" putting much of the $1.3 trillion of LNG investments at risk.

- July 13, 2018 – A retrospective look at the risk management and risk governance used to develop and construct three LNG facilities in Gladstone, Australia evaluated the process by which multiple stakeholders—including government, business, community, and environmental groups—contributed to decision-making and management. The framework developed by the International Risk Governance Council was used for comparison. Environmental, social, and economic impacts occurred during construction, including death of harbor marine life, increased housing prices, and increased cost of living. Several problems in risk assessment and management were identified, including lack of cooperation between organizations at the onset of construction; disagreement as to whether monitoring and compliance mechanisms were adequate; and concern that the government was reactive to problems, rather than attempting to prevent or mitigate risks. Several recommendations were made to improve the risk management process of future projects.[2175]

- February 12, 2018 – Two LNG storage tanks were shut down at Cheniere Energy's Sabine Pass export facility after leaking LNG was found in a containment ditch around one of the tanks and 14 separate natural gas leaks were discovered around the base of a second tank. The Sabine Pass facility is located on the U.S. Gulf Coast on the border

[2173] Jenny Mandel, "Trump LNG Rule: Will It Address 'Catastrophic' Risks?," *E&E News*, July 22, 2019, https://web.archive.org/web/20190722172209/https://www.eenews.net/stories/1060771257.
[2174] Matt Egan, "America's Liquefied Natural Gas Boom May Be on a Collision Course with Climate Change," *CNN Business*, July 1, 2019, https://www.cnn.com/2019/07/01/business/lng-boom-environment-climate-change/index.html.
[2175] R. G. van der Vegt, "Risk Assessment and Risk Governance of Liquefied Natural Gas Development in Gladstone, Australia: Risk Assessment and Risk Governance of LNG Development," *Risk Analysis* 38, no. 9 (2018): 1830–46, https://doi.org/10.1111/risa.12977.

between Texas and Louisiana. Emergency procedures were put into place to assure the safety of the 107 on-site workers, but the public was not notified about this incident until more than two weeks later. Inspection revealed four cracks up to six feet long in the outer shell of the tank that had leaked LNG. These tanks are double walled, but only the inner tank is designed to tolerate the super-chilled temperature of LNG. The outer tank, rated to only -25° F, became brittle upon contact with -260° F LNG. The resulting investigation uncovered a long history of safety issues at this plant, including 11 other incidents involving these tanks that had occurred as far back as 2008 (when Sabine Pass was operating as an LNG import facility) after the federal Pipeline and Hazardous Materials Safety Administration (PHMSA) ordered Cheniere to conduct a root cause analysis and turn over records of any prior leaks.[2176] The agency also issued an order stating, "continued operation of the affected tanks without corrective measures is or would be hazardous to life, property, and the environment." Sabine Pass facility was required to receive written authorization from the Federal Energy Regulatory Commission (FERC) before the tanks could be put back in service.[2177] As part of a later hearing, parts of which were closed to the press and to the public, an accident investigator with PHMSA said that she had struggled with the company to get information "timely and in enough detail."[2178] In April 2018, the parties agreed to resolve the issue without administrative proceedings or litigation.[2179]

- November 20, 2017 – Using a hybrid lifecycle and energy strategy analysis, a team of energy researchers investigated the potential climate impacts of U.S. LNG exports to Asia. They found that gas emissions were widely variable, dependent on the specific destination and the ultimate purpose for which the gas is used. Despite this range, under a scenario in which U.S. LNG exports continue to rise, "emissions are not likely to decrease and may increase significantly" because of additional energy demand, higher U.S. emissions, and increased methane leakage. The study also predicted that increased LNG exports could actually prolong the lifespans of coal-fired plants within the United States. All together, these factors, "have the very real potential to undermine any prospective climate benefit in the long run." Going forward, policymakers must consider "the complete climate ramifications of LNG exports."[2180] *E&E News*, reporting on the study, quoted one of the authors as saying, "The implications of our paper are that the greenhouse gas impacts from exporting U.S. natural gas…here at home and abroad, can be very, very bad."[2181]

[2176] Jenny Mandel and Mike Soraghan, "Feds Order Partial Shutdown at Cheniere LNG Export Site," *E&E News*, February 12, 2018, https://web.archive.org/web/20180212171644/https://www.eenews.net/stories/1060073537.
[2177] Mark Schleifstein, "Sabine Pass LNG Ordered to Shut down Leaking Gas Storage Tanks," *The Times-Picayune*, February 10, 2018, https://www.nola.com/news/environment/article_e93f653c-18d3-5016-abc6-47cdd7370b90.html.
[2178] Edward Klump and Mike Soraghan, "Cheniere Says No Public Danger from Sabine Pass Leaks," *E&E News*, March 22, 2018, https://web.archive.org/web/20180322180240/https://www.eenews.net/stories/1060077135.
[2179] "Cheniere Settles Sabine Pass LNG Tanks Issue with PHMSA," *LNG World News*, April 24, 2018, https://www.offshore-energy.biz/cheniere-settles-sabine-pass-lng-tanks-issue-with-phmsa/.
[2180] Alexander Q. Gilbert and Benjamin K. Sovacool, "US Liquefied Natural Gas (LNG) Exports: Boom or Bust for the Global Climate?," *Energy* 141 (December 2017): 1671–80, https://doi.org/10.1016/j.energy.2017.11.098.
[2181] Ellen M. Gilmer and Jenny Mandel, "Increased LNG Exports Would Spell Trouble for Climate – Study," *E&E News*, December 15, 2017, https://web.archive.org/web/20180730192553/https://www.eenews.net/stories/1060069129.

- November 16, 2017 – A legal analysis in the *Energy Law Journal* examined the contested decision by the Federal Energy Regulatory Commission to authorize the expansion of the Dominion Cove Point LNG facility to allow for export as well as import activity, by examining the multiple direct and indirect effects of the expansion. Direct effects included impacts on water quality, the North Atlantic right whale, and the public safety of local residents. Indirect effects included an increase in domestic fracking, increase in tanker traffic, and exacerbation of climate change as export markets increase demand for natural gas. Because this latter set of problems is not directly related to facility expansion but rather to increased LNG exports, two different federal agencies have jurisdiction. The responsibilities of FERC and the Department of Energy (DOE) were clarified regarding this distinction. FERC handles the environmental review, while the DOE regulates export of LNG. In the case of Cove Point, FERC had issued a finding of no significant impact and was therefore not legally required to investigate indirect effects such as climate change. The analysis therefore concluded that FERC followed proper procedures and that the DOE would be a more appropriate target of legal action because of its control over LNG exports. This analysis reveals the diffusion of responsibility among federal agencies regulating LNG facilities and the legal difficulties of addressing far-removed, indirect harms.[2182]

- July 25, 2017 – Citing volatile market conditions, Malaysia's energy giant Petronas canceled plans for a massive LNG export terminal at the mouth of the Skeena River on British Columbia's remote northwest coast in Canada. As reported extensively by *The Tyee,* the project was the target of intense protest by First Nations people and the subject of many lawsuits, as it threatened public health and would industrialize pristine salmon habitat. "At one time as many as twenty LNG projects were proposed for coastal communities, but not one has been built. The majority of largely Asian-backed proponents have now canceled or deferred their projects. A 50 percent drop in global oil prices combined with a 70 percent drop in global LNG prices forced Petronas to…scuttle a number of projects over the last two years."[2183]

- July 10, 2017 – Using a lifecycle assessment and optimization analysis to forecast the environmental impacts of LNG, researchers modeled three usage scenarios: hydrogen production; electricity generation; and vehicle fuel. The model assumed LNG transport by pipeline only, and not by tanker. The highest environmental impact in each case was global warming potential (GWP), and the highest GWP occurred when LNG was used as vehicle fuel.[2184]

[2182] K. Rhodes, "The Weakest Link: The Consistent Refusal to Consider Far-Removed Indirect Effects of the Expansion of LNG Terminals," *Energy Law Journal* 38, no. 2 (2017): 431–53.
[2183] Andrew Nikiforuk, "'Basic Economics' Kill $11-Billion LNG Project on BC's Coast," *The Tyee*, July 25, 2017, https://thetyee.ca/News/2017/07/25/LNG-Project-BC-Coast-Killed/.
[2184] Yun Zhang et al., "Life Cycle Assessment and Optimization Analysis of Different LNG Usage Scenarios," *The International Journal of Life Cycle Assessment* 23, no. 6 (2018): 1218–27, https://doi.org/10.1007/s11367-017-1347-2.

- April 11, 2017 – The World Bank Group, which makes loans to developing nations for capital projects like infrastructure, released environmental, health, and safety guidelines for LNG facilities. These guidelines address the risks of spills, fire, explosions, air quality impacts, venting, flaring, and fugitive emissions. Also addressed was the danger of "roll-over," a phenomenon that occurs when layers of LNG of different density in a storage tank mix inappropriately. The result can be a rapid release of vapors and rise in pressure, potentially leading to catastrophic structural damage of the tank.[2185]

- March 30, 2017 – Transportation researchers identified and assessed potential risks to public safety from LNG transport on inland waterways and as a fuel for vessels and ferries. The hazards included the possibility of collision with other ships or with stationary objects such as bridges, as well as the threats of vapor release, flash and jet fires, boiling liquid expanding vapor explosion, and rapid phase transition. Firefighting strategies for different scenarios were proposed.[2186]

- March 9, 2017 – Liquefaction, LNG transport, and LNG evaporation determined more than 50 percent of LNG's global warming potential (GWP) in a "cradle to gate" life cycle analysis of LNG imported to the UK from Qatar. The analysis confirmed the dangerous effect of fugitive methane emissions on the total GWP of the supply chain. Other important parameters affecting GWP included the shipping distance and the tank volume.[2187]

- December 22, 2016 – Methane emissions from the heavy-duty transportation sector have climate change implications, according to a "pump-to-wheels" evaluation of natural gas powered vehicles and the compressed natural gas and LNG stations that fuel them. While fueling stations themselves leak methane, tailpipe and crankcase emissions were the highest sources.[2188]

- May 2, 2016 –The potential economic and greenhouse gas (GHG) impacts of importing LNG to Hawaii for electricity generation was modeled. Methane is a potent GHG, and although the use of LNG would decrease the local GHG output of Hawaii's electrical sector, lifecycle (global) GHG emissions would likely increase. This study did not examine other potential environmental impacts of LNG. Currently, the majority of Hawaii's electricity is provided by oil-fired generation.[2189]

[2185] World Bank Group, "Environmental, Health, and Safety Guidelines for Liquefied Natural Gas," 2017, https://www.ifc.org/wps/wcm/connect/Topics_Ext_Content/IFC_External_Corporate_Site/Sustainability-At-IFC/Publications/Publications_Policy_EHS-LNG.
[2186] Andrea Galieriková, Tomáš Kalina, and Jarmila Sosedová, "Threats and Risks during Transportation of LNG on European Inland Waterways," *Transport Problems* 12, no. 1 (2017): 73–81, https://doi.org/10.20858/tp.2017.12.1.7.
[2187] Carla Tagliaferri et al., "Liquefied Natural Gas for the UK: A Life Cycle Assessment," *The International Journal of Life Cycle Assessment* 22, no. 12 (2017): 1944–56, https://doi.org/10.1007/s11367-017-1285-z.
[2188] Nigel N. Clark et al., "Pump-to-Wheels Methane Emissions from the Heavy-Duty Transportation Sector," *Environmental Science & Technology* 51, no. 2 (2017): 968–76, https://doi.org/10.1021/acs.est.5b06059.
[2189] Makena Coffman et al., "Economic and GHG Impacts of Natural Gas for Hawaii," *Environmental Economics and Policy Studies* 19, no. 3 (2017): 519–36, https://doi.org/10.1007/s10018-016-0157-2.

- November 12, 2015 – New York Governor Andrew Cuomo rejected a heavily contested proposal to construct an LNG terminal 19 miles off the coast of Long Island. From his letter to the Maritime Administration: "The security and economic risks far outweigh any potential benefits….The potential for disaster with this project during extreme weather or amid other security risks is simply unacceptable." The governor also noted the risks posed to scallop and squid fisheries as well as the project's conflict with a proposed large-scale, offshore wind farm.[2190]

- September 30, 2015 – Measurements of the gaseous and particulate emissions of a cruise ferry on the Baltic Sea using a dual-fuel engine showed that LNG is not a clean fuel for ships. Methane made up about 85 percent of the vessel's hydrocarbon emissions. Particulate emissions showed a huge amount of volatile and nonvolatile particles, both of which are hazardous to human health.[2191]

- September 26, 2014 – The U.S. Government Accountability Office (GAO) issued a report of the federal process for reviewing applications to export LNG. As part of the process, the DOE and FERC consider public comment. Numerous environmental concerns include the risk that exports will increase hydro-fracking for natural gas, along with its associated environmental effects and greenhouse gas emissions. Under the National Environmental Policy Act, the DOE must consider the environmental effects of its decisions.[2192]

- April 23, 2014 –The dynamics and hazards from a LNG spill are not well understood and require further research, according to a comprehensive review of research into the LNG production chain from Australia that examined vapor production, vapor dispersion, and mechanisms of combustion. Noting the "intrinsic process safety issues" of LNG as well as potential attraction as a terrorist target, authors described various threats to human safety, including pool fires, jet fires, and vapor cloud explosions.[2193]

- December 14, 2009 – Certain LNG hazards are not "understood well enough to support a terminal siting approval," according to a Congressional Research Service (CRS) report that summarizes LNG hazards in the context of federal rules related to where LNG terminals are located. Potential risks include pool fires and flammable vapor clouds, as well as the possibility of terrorist attacks. The analysis points out the need for additional LNG safety research.[2194]

[2190] Marc Santora, "Cuomo Rejects Natural Gas Port Proposed Off Long Island," *The New York Times*, November 12, 2015, sec. New York, https://www.nytimes.com/2015/11/13/nyregion/cuomo-rejects-natural-gas-port-proposed-off-long-island.html.
[2191] Maria Anderson, Kent Salo, and Erik Fridell, "Particle- and Gaseous Emissions from an LNG Powered Ship," *Environmental Science & Technology* 49, no. 20 (2015), https://doi.org/10.1021/acs.est.5b02678.
[2192] U.S. Government Accountability Office, "Federal Approval Process for Liquefied Natural Gas Exports," Congressional Report, September 2014, https://www.gao.gov/assets/gao-14-762.pdf.
[2193] Walter Chukwunonso Ikealumba and Hongwei Wu, "Some Recent Advances in Liquefied Natural Gas (LNG) Production, Spill, Dispersion, and Safety," *Energy & Fuels* 28, no. 6 (2014): 3556–86, https://doi.org/10.1021/ef500626u.
[2194] [Name Redacted], "Liquefied Natural Gas (LNG) Import Terminals: Siting, Safety, and Regulation," Congressional Research Report, December 2009.

- July 7, 2009 – Because LNG projects are among the most expensive energy projects, the reserves of gas to justify the investment need to be large enough to guarantee about 30 years of production, according to a report by the Joint Research Centre of the European Union.[2195]

- May 13, 2008 – LNG infrastructure is "inherently hazardous and it is potentially attractive to terrorists," according to a CRS study that was prepared at a time when the United States was a net importer of LNG. Security of tankers, import terminals, and inland storage plants were identified as issues of concern. Serious risks include pool fires with intense heat, which can occur when LNG spills near an ignition source; flammable vapor clouds that can drift until reaching an ignition source; and a rapid phase transition that can generate a flameless explosion. As per this report, there have been 13 serious accidents at onshore LNG terminals since 1944.[2196]

- February 22, 2007 – The GAO examined the results of studies on the consequences of an LNG spill and discussed expert opinion about the consequences of a terrorist attack on an LNG tanker. The studies indicate that 30 seconds of exposure to the heat of an LNG fire could cause burns up to a distance of about one mile. The experts concluded that this would be the most likely public safety hazard, with the risk of explosion less likely. Recommendations were made for further studies, including evaluating the possibility of "cascading failure," where multiple LNG tanks on a ship might fail in sequence.[2197]

- September 9, 2003 – As part of a larger investigation of potential terrorist targets in wake of the 9/11 attacks, the CRS provided a background report to the U.S. Congress on the security of LNG terminals in the United States. At the time, the United States was a net importer of natural gas, and LNG was shipped from overseas to U.S. ports. CRS identified LNG tanker ships and storage infrastructure as "vulnerable to terrorism," noting that tankers could be turned as weapons against coastal cities and that inland LNG facilities are typically located near large population centers. The CRS further noted that the public cost of security for LNG shipments, via Coast Guard escorts of tankers through coastal shipping channels, was considerable ($40,000-$80,000 per tanker).[2198]

- August 1, 1995 – The U.S. Department of Transportation identified three important hazardous properties of LNG: flammability hazards (fire or explosion from ignition of leaks); toxicity hazards (asphyxiation from exposure to non-odorized fuel gas); cryogenic

[2195] Boyan Kavalov, Hrvoje Petric, and Aliki Georgakaki, "Liquefied Natural Gas for Europe: Some Important Issues for Consideration." (Publications Office, 2009), https://publications.jrc.ec.europa.eu/repository/handle/JRC47887.
[2196] Paul W. Parfomak, "Liquefied Natural Gas (LNG) Infrastructure Security: Issues for Congress," Congressional Research Report (Library of Congress, Congressional Research Service, May 2008), https://www.hsdl.org/?view&did=486464.
[2197] U.S. Government Accountability Office, "Public Safety Consequences of a Terrorist Attack on a Tanker Carrying Liquefied Natural Gas Need Clarification," February 2007, https://www.gao.gov/new.items/d07316.pdf.
[2198] Paul W. Parfomak, "Liquefied Natural Gas (LNG) Infrastructure Security: Background and Issues for Congress" (Library of Congress, Congressional Research Service, September 9, 2003), https://apps.dtic.mil/sti/pdfs/ADA426272.pdf.

hazards (personal injury plus structural failure of equipment from prolonged exposure to extremely cold temperatures.)[2199]

Gas-fired power plants

By 2016, natural gas-fired power plants had surpassed coal-burning plants as the leading source of electrical generation in the United States.

There are two types of gas-fueled power plants: combined cycle plants and simple cycle plants. Both types are major emitters of carbon dioxide, uncombusted methane, and nitrogen oxides, which contribute to the formation of ground-level ozone (smog). Combined cycle gas plants reuse waste heat to generate additional electricity and are roughly equivalent in efficiency to an older coal plant. Simple cycle gas plants—also called peaker plants—can be turned on and off faster to meet fluctuating energy demands when electricity needs peak, but they are much less efficient and more polluting than combined cycle plants. Simple cycle peaker plants can often generate more nitrogen oxides and carbon monoxide than coal plants.

Gas-fired combined cycle plants were formerly promoted as a bridge to reduce emissions while renewables ramp up. However, renewable prices have fallen low enough to allow a transition directly from coal to solar and wind power, revealing that gas plants, with long returns on investment, are more barrier than bridge and serve to delay a speedy transition to renewable energy. At the same time, the lifecycle greenhouse gas emissions of both types of gas-fired power plants have been shown to be far higher than previously estimated. In Virginia, carbon dioxide emissions from electricity generation rose rather than fell after the state retired its fleet of coal plants and embarked on a massive build-out of gas-burning plants. Gas plants are also prone to failure during cold snaps and extreme winter storms due to loss of compression and freeze-ups in the pipelines that service them.

New natural gas plants, which have an operational lifespan of 40 years, lock in demand for gas for longer than current climate scenarios dictate, which call for net-zero carbon emissions by mid-century. Gas plants thus risk becoming stranded assets, as they would need to be decommissioned well before the end of their lifespan.

Gas-fired simple cycle plants that are used on demand as peakers have become obsolete as battery technology now allows for the storage of renewable energy, eliminating the need for gas plants to provide power in times of peak demand.

Natural gas power plants are a major emitter of smog-making nitrogen oxides. Emerging evidence shows a variety of health impacts to people living near gas-fired power plants.

[2199] Michael J. Murphy et al., "Clean Air Program: Summary Assessment of the Safety, Health, Environmental and System Risks of Alternative Fuel" (U.S. Department of Transportation, Federal Transit Administration, August 1, 1995), https://doi.org/10.21949/1403909.

- January 11, 2023 – From December 21 to 26, 2022, Winter Storm Elliott created blizzard conditions and record cold temperatures across the United States and Canada. More than six million households in the United States were without power for some part of the five-day storm, with the Buffalo, New York region especially hard hit as utilities struggled and, in many places, failed to deliver increased electricity during the three peak demand days. A subsequent investigation revealed that gas-fired power plants were particularly prone to failure during Winter Storm Elliot, highlighting the vulnerability of natural gas supplies to freeze up during cold snaps and storms. On Christmas Eve, more than 46,000 megawatts of capacity failed to perform with 70 percent of that total coming from gas-fired power plants. Many of these plants failed because the extreme cold disrupted the flow of gas through the pipelines that served them, as a result of freeze-ups as well as loss of compression. Frigid temperatures also impeded operations at well sites, gathering stations, and compressor stations. U.S. gas production declined markedly during the storm. Gas production in Pennsylvania fell by 20 percent, and gas production in Ohio plunged by more than 50 percent.[2200, 2201, 2202]

- July 2, 2021 – In New York State, the proposed rebuilding of the Danskammer gas-fired power plant in the environmental justice community of Newburgh prompted day-long hearings on the part of two state agencies, the Public Service Commission, which oversees the state's power plant siting laws, and the New York Department of Environmental Conservation (DEC), which permits air pollutants and other discharges. The Danskammer plant is the first large-scale gas-fired power plant to be considered by New York state authorities since the 2019 passage of the Climate Leadership and Community Protection Act (CLCPA). This legislation calls for sharp, rapid reductions in the use of all fossil fuels, including natural gas, in New York State and therefore the Danskammer plant would interfere with its attainment, according to both testimony and the DEC.[2203]

- June 18, 2021 – Energy stakeholders are split over California's inclusion of fossil fuel resources in a proposed procurement package. At issue is ensuring grid reliability due to the closure of a nuclear power plant and unreliable and aging power plants. Environmental groups maintained that modeling has not indicated a need for additional fossil fuel resources in the state.[2204]

[2200] PJM, "Winter Storm Elliot," https://www.pjm.com/-/media/committees-groups/committees/oc/2023/20230112/item-02---overview-of-winter-storm-elliott-weather-event.ashx.
[2201] Nicholas Cunningham, "Winter Storm U.S. Power Outages Reveal Fossil Gas Limits," *Gas Outlook*, January 19, 2023, https://www.pjm.com/-/media/committees-groups/committees/oc/2023/20230112/item-02---overview-of-winter-storm-elliott-weather-event.ashx.
[2202] Laila Kearney, "Grid Operator PJM Probes U.S. Power Supply Woes during December Storm," *Reuters*, January 13, 2023, https://www.reuters.com/world/us/grid-operator-pjm-probes-us-power-supply-woes-during-december-storm-2023-01-12/.
[2203] Rick Karlin, "Plan for Hudson Valley Power Plant Collides with State's New Green Law," *Albany Times Union*, July 2, 2021, https://www.timesunion.com/news/article/Public-comment-period-starts-reigniting-gas-16290500.php.
[2204] Kavya Balarman, "California Groups Clash Over Gas in 11.5 GW Procurement Proposal as CAISO Calls for Conservation," *Utility Dive*, June 18, 2021, https://www.utilitydive.com/news/california-clash-gas-11-5-gw-proposal-caiso/602039/.

- May 21, 2021 – President Biden set a 15-year deadline for a zero-emissions electric grid. A new gas plant has a projected lifespan of 40 years. This discrepancy places any new power plant into a timeslot which falls outside of that carbon neutral timeline. At least eight large utilities in the U.S. are currently building new gas plants right now, and another five are considering doing so.[2205]

- April 22, 2021 – The Danskammer power plant in Newburgh is testing New York's Climate Leadership and Community Protection Act (CLCPA), passed in 2019, and the state's commitment to reducing fossil fuel emissions, according to an investigation published jointly by *City & State New York* and *New York Focus*. An advisory panel to the Climate Action Council planned to recommend that New York declare a moratorium on new natural gas facilities.[2206]

- April 1, 2021 – Ocean water is customarily used to cool some machinery at older natural gas plants on the California coast, a practice resulting in releases of much warmer water back into the ocean, harming fish and the environment. Local politicians, including the mayor of Redondo Beach, have opposed this practice and have called for the closure of these archaic power plants. However, power shortages during the hottest summer on record in 2020 prompted the Statewide Advisory Committee on Cooling Water Intake Structures to vote to recommend a delay of the planned shutdown of the Redondo Beach gas plant until the end of 2023.[2207]

- February 2, 2021 – The federally owned electric utility corporation, Tennessee Valley Authority (TVA), is proposing to replace its aging coal plants with natural gas plants. Over the past decade and a half, the sources of TVA's electricity generation have shifted away from coal toward more natural gas and nuclear power. Among the 50 biggest U.S. utilities, TVA had the second biggest increase planned in new natural gas production, with more than 3 gigawatts of capacity in its long-range plans. TVA provides electricity to all of Tennessee as well as parts of Alabama, Georgia, Kentucky, Mississippi, North Carolina, and Virginia.[2208]

- January 21, 2021 – The largest gas-fired power plant in Europe, under development by Drax in North Yorkshire in the United Kingdom would, all by itself, account for 75 percent of emissions from the UK's power sector when it becomes fully operational. The

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[2205] Josh Saul, "New Gas Plants Threaten Carbon Hangover Long Past Biden Deadline," Bloomberg Green, 21 2021, https://www.bloomberg.com/news/features/2021-05-21/lifespan-of-new-u-s-gas-plants-exceeds-net-zero-climate-goals.
[2206] Lee Harris, "Gas Plant in Newburgh Tests Limits of NY's Landmark Climate Law," *City & State New York*, April 22, 2021, https://www.cityandstateny.com/articles/policy/energy-environment/gas-plant-newburgh-tests-limits-nys-landmark-climate-law.html.
[2207] Sammy Roth, "How a Beachfront Gas Plant Explains California's Energy Problems," *Los Angeles Times*, April 1, 2021, https://www.latimes.com/environment/newsletter/2021-04-01/how-a-beachfront-gas-plant-explains-californias-energy-problems-boiling-point.
[2208] Dave Flessner, "TVA Proposes to Build New Gas Plants at Shuttered Coal Sites," *Chatanooga Times Free Press*, February 2, 2021, https://www.timesfreepress.com/news/business/aroundregion/story/2021/feb/02/tvproposes-build-new-gplants-shuttered-coal-s/540871/.

Planning Inspectorate, a U.K. executive agency on land use planning, recommended that ministers refuse permission for the plant on the grounds that it would undermine the government's commitment, as codified in the Climate Change Act 2008, to cut greenhouse emissions. However, the Inspectorate was overruled.[2209]

- September 3, 2020 – Between 2000-2018, the proportion of U.S. electricity generated by coal fell by half (from 52 percent to 27 percent) and electricity from burning natural gas more than doubled (from 16 percent to 35 percent). Over the same time period, carbon dioxide emissions from the U.S. power sectors dropped by 24 percent. However, using a commitment accounting approach, an analysis of U.S. power plants found that coal-to-gas switching in the power sector has, in fact, failed to lower greenhouse gas emissions. Commitment accounting takes into account cumulative emissions across the entire assumed operating lifecycle of coal and gas plants. Because coal plants nearing the end of their operation lifespans tend to be replaced by new gas plants that have more future longevity, substituting gas plants for coal plants has not functioned to decreased committed emissions, even when a modest upstream methane leakage rate of 3 percent is assumed. "Thus, although annual emissions have fallen, cumulative future emissions will not be substantially lower unless existing coal and gas plants operate at significantly lower rates than they have historically. Moreover, our estimates of committed emissions for U.S. coal and gas plants finds steep reductions in plant use and/or early retirements are already needed for the country to meet its targets under the Paris climate agreement—even if no new fossil capacity is added."[2210]

- July 15, 2020 – The municipality of Cornwall, New York passed a resolution opposing the expansion of the Danskammer power plant, which is seeking to retool its gas-fired peaker plant in the Hudson River Valley into a continuously operating baseload facility. In so doing, Cornwall joined 20+ other towns and cities in opposing the project.[2211] The Danskammer plant would increase nitrogen oxides, ozone, and particulate matter in the area and increase greenhouse gas emissions. Permitted through 2053, its operation would also exceed the state's timeline to reach 100 percent clean energy by 2040. Further, the downwind city of Newburgh is an environmental justice community. As noted by the City of Hudson Common Council when it passed its own resolution, the proposal, if approved, "will continue the state's reliance upon fossil fuels and will not promote the state's climate change policy."[2212] The proposal is currently under review by the New York State Public Service Commission. A decision will be made by a State Siting Board.

[2209] Damian Carrington, "Legal Bid to Stop UK Building Europe's Biggest Gas Power Plant Fails," *The Guardian*, January 21, 2021, https://www.theguardian.com/environment/2021/jan/21/climate-crisis-uk-legal-bid-stop-biggest-gas-power-station-europe-fails?CMP=twt_a-environment_b-gdneco.
[2210] Christine Shearer et al., "Committed Emissions of the U.S. Power Sector, 2000–2018," *AGU Advances* 1 (2020): e2020AV000162, https://doi.org/10.1029/2020AV000162.
[2211] Helu Wang, "Cornwall Joins the Force Opposing Danskammer Power Plant," *Times Herald-Record*, July 15, 2020, https://www.recordonline.com/story/news/2020/07/15/cornwall-joins-20-ny-municipalities-oppose-danskammer-power-plant/5427624002/.
[2212] Abby Hoover, "Hudson Joins Riverfront Cities in Opposing Power Plant Expansion," *HudsonValley360*, May 29, 2020, https://www.hudsonvalley360.com/news/columbiacounty/hudson-joins-riverfront-cities-in-opposing-power-plant-expansion/article_96be26b1-0302-56aa-8c0d-64d0036cdafb.html.

- July 8, 2020 – Samples of water, sediments, soil, and biota were analyzed for concentration of potentially toxic trace metals—arsenic, cadmium, chromium, mercury, lead, zinc—in a lagoon next to a gas and oil power plant in Lagos, Nigeria.[2213] Rigorous sampling and analysis of crabs and shrimp, which are ingested by the local population as an important food source, showed bioaccumulation of cadmium, lead, mercury, and zinc. Another pathway of exposure was via air, as atmospheric deposition of pollutants was believed to be responsible for chromium measured in proximal soil samples. And since the concentration of arsenic, cadmium, chromium, and lead in the lagoon water decreased steadily with distance away from the plant, the authors concluded that their levels in the lagoon were influenced by operations of the power plant.

- May 22, 2020 – The approval of the largest power plant in Europe, which is being developed by Drax in North Yorkshire, could account for 75 percent of the UK's power sector emissions when fully operational. The UK's planning inspectorate recommended that ministers refuse permission for the 3.6GW gas plant because it "would undermine the government's commitment, as set out in the Climate Change Act 2008, to cut greenhouse emissions" by having "significant adverse effects."[2214] This was the first time this group had ever taken such an action. Despite this recommendation, the secretary of state for business, energy and industrial strategy rejected the advice and approved the project in October 2019.

- May 22, 2020 – A new set of data visualization tools from Physicians, Scientists, and Engineers for Healthy Energy (PSE) demonstrates that peaker generating natural gas plants causing the greatest health burdens can be retired and replaced with energy storage. For each state with storage-friendly policies—California, Nevada, Arizona, New Mexico, Texas, Florida, New York, New Jersey, and Massachusetts—there is a report with data visualization. According to PSE's Director of Research Elena Krieger, "Regulators and policymakers can use our findings to inform decisions related to energy storage and clean energy targets, greenhouse gas and criteria pollutant emission reductions, and investments to improve clean energy access for under-served and vulnerable communities."[2215]

- May 20, 2020 – A review of EPA emissions data show that Virginia is an outlier for U.S. electricity emissions reductions, attributable to the state's massive build-out of natural gas plants.[2216] Although all but two of its six remaining coal plants have closed, the state's replacement with gas for electricity generation has led to soaring carbon dioxide

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[2213] Gideon A. Idowu et al., "Impact of Gas and Oil-Fired Power Plants on Proximal Water and Soil Environments: Case Study of Egbin Power Plant, Ikorodu, Lagos State, Nigeria," *SN Applied Sciences* 2, no. 8 (2020): 1352, https://doi.org/10.1007/s42452-020-3150-0.
[2214] Damian Carrington, "UK Approval for Biggest Gas Power Station in Europe Ruled Legal," *The Guardian*, May 22, 2020, sec. Environment, https://www.theguardian.com/environment/2020/may/22/uk-approval-for-biggest-gas-power-station-europe-ruled-legal-high-court-climate-planning.
[2215] William Driscoll, "Replacing Peakers with Storage to Achieve the Greatest Health Benefit," *PV Magazine*, May 22, 2020, https://pv-magazine-usa.com/2020/05/22/replacing-peakers-with-storage-to-achieve-the-greatest-health-benefit/.
[2216] Benjamin Storrow, "Coal Plants Disappear in Va. But CO2 Is Rising," *E&E News*, May 20, 2020, https://web.archive.org/web/20200527214244/https://www.eenews.net/stories/1063179963.

emissions: about four million tons in 2009 to almost 25 million tons in 2019, accounting for 80 percent of all power sector emissions in Virginia. The low cost of fracked gas served as an incentive to the power plant boom as did state legislation that encouraged utilities to build more power plants.

- May 4, 2020 – Tens of billions of dollars of shareholder risk accompanies new natural gas infrastructure according to a report reviewed by Forbes.[2217] The report by the organization Energy Innovation and the shareholder advocacy group As You Sow argues that utility investment in new natural gas infrastructure only compounds risks for investors, consumers, and society. Due to incompatibilities with climate goals, as well as intense competition from renewables, the report advocates for a clean energy transition as the more affordable, less risky option. The article reinforced the report's findings, citing studies by the National Renewable Energy Laboratory, National Oceanic and Atmospheric Administration, Evolved Energy, and Vibrant Clean Energy, which found that at least 80 percent our electricity could be generated from renewable sources without reliability or affordability issues.

- April 26, 2020 – Air pollution is strongly associated with cardiovascular disease. In one of the first studies of its kind, a research team investigated the effects of air pollution exposure among workers in natural gas-fired power plants in Nigeria and matched them with healthy controls.[2218] They found increased systolic blood pressure, increased pulse rate, and higher levels of the inflammatory marker C-reactive protein in the workers compared to the controls. The longer the workers were employed there, the more abnormal their results.

- April 8, 2020 – New York State could have met the need for electricity with renewables, storage, and energy efficiency measures following the closure of the Indian Point nuclear power plant without constructing two major gas-fired power plants, according to an analysis by PSE Healthy Energy.[2219] The report concludes expanding gas infrastructure risks creating stranded assets and threatens to undermine New York's climate goals, and that employing clean resources instead of gas "could bring co-benefits like improved local air quality from the reduction of criteria air pollutants emitted by natural gas plants and enhanced grid resiliency in the case of natural disasters or other emergencies."

- March 12, 2020 – The Leviathan natural gas fields, discovered ten years earlier off the coast of Haifa in Israel, became operational in December 2019. Hundreds of billions of dollars in revenue were anticipated. However, the economic downturn, a European Union

[2217] Michael O'Boyle, "Utility Investors Risk Billions In Rush To Natural Gas: Is It A Bridge To Climate Breakdown?," *Forbes*, March 4, 2020, sec. Energy, https://www.forbes.com/sites/energyinnovation/2020/03/04/utility-investors-risk-billions-in-rush-to-natural-gas-is-it-a-bridge-to-climate-breakdown/.
[2218] C. D. Ekpruke and V. I. Iyawe, "Cardiovascular System Response to Chronic Exposure to Emissions from Gas Turbines Power Plants," *World Journal of Cardiovascular Diseases* 10, no. 04 (2020): 208–24, https://doi.org/10.4236/wjcd.2020.104020.
[2219] Annie Dillon, "Evaluating the Potential for Renewables, Storage, and Energy Efficiency to Offset Retiring Nuclear Power Generation in New York," *PSE Healthy Energy*, April 8, 2020, https://www.psehealthyenergy.org/our-work/publications/archive/research-brief-new-york-renewables-indian-point/.

carbon tax imposed on imported fossil fuels, decreased demand, falling costs of renewables, and greater concern about climate change combined to reduce the expected windfall by a factor of ten, raising questions about further investments in gas infrastructure and in building gas-fired power plants that will be obsolete within 20 years.[2220]

- February 27, 2020 – The monthly report by an energy analyst from the Australian National University's Crawford School of Public Policy challenged the national government's investment in a program that proposes up to five new gas-powered power plants.[2221] The monthly National Energy Emissions Audit suggested instead that to increase supply, currently functioning power plants can operate at greater capacity. According to the Audit, combined-cycle gas plants in the national grid were operating at only 30 percent capacity. "In reality, gas is expensive, it's high-polluting and, as this research shows, it is under-performing… Given this, why would we underwrite new gas-fired plants?"[2222]

- January 6, 2020 – The Cayuga Power Plant in Lansing, New York ceased generating power on August 29, 2019 after plans to convert the facility from a coal plant to a natural gas peaker plant were scrapped in the face of massive public opposition and after electricity transmission upgrades made electricity generated from this plant unnecessary. An advisory committee to the Lansing Town Council will oversee the future of the site. Current plans are to convert the facility into a data center with energy storage.[2223]

- September 9, 2019 – Renewables and large storage batteries will put gas-fired powered plants out of business, according to an analysis by *Bloomberg*: "It will happen so quickly that gas plants now on the drawing boards will become uneconomical before their owners are finished paying for them."[2224]

- September 9, 2019 – An analysis by *USA Today* found as many as 177 natural gas power plants in the United States "planned, under construction or announced," with close to 2,000 currently in service. In addition to the potentially catastrophic climate implications of increased methane emissions from such plants, figures show that their cost "will be more expensive than renewable alternatives" and that incentives reward utility companies

[2220] Nir Hasson, "Israel Needs to Let Go of the Natural Gas Fantasy," *Haaretz*, March 12, 2020, https://www.haaretz.com/israel-news/.premium.MAGAZINE-israel-needs-to-let-go-of-the-natural-gas-fantasy-1.8669944?=&ts=_1584147526761.
[2221] Hugh Saddler, "No Case for More Gas: National Energy Emission Audit," *The Australia Institute*, February 27, 2020, https://australiainstitute.org.au/post/no-case-for-more-gas-national-energy-emission-audit/.
[2222] Adam Morton, "'Expensive and Underperforming': Energy Audit Finds Gas Power Running Well below Capacity," *The Guardian*, March 7, 2020, sec. Environment, https://www.theguardian.com/environment/2020/mar/08/expensive-and-underperforming-energy-audit-finds-gas-power-running-well-below-capacity.
[2223] Andrew Sullivan, "What's next for the Cayuga Power Plant?," *Ithaca Times*, January 6, 2020, https://www.ithaca.com/news/lansing/what-s-next-for-the-cayuga-power-plant/article_171878da-2d96-11ea-b326-47a464efe599.html.
[2224] David R. Baker, "Gas Plants Will Get Crushed by Wind, Solar by 2035, Study Says," *Bloomberg*, September 9, 2019, https://www.bloomberg.com/news/articles/2019-09-09/gas-plants-will-get-crushed-by-wind-solar-by-2035-study-says.

for building them instead of turning to renewable alternatives. That is, in most of the country "a combination of state-level rate-setting requirements and regional market rules" lead to compensation structures that favor coal and natural gas over renewable sources of energy.[2225]

- July 8, 2019 – *S&P Global* reported that economics are causing some utilities to consider renewable energy projects over gas-fired power plant investments.[2226] States that have placed moratoria or rejected plans for new gas-powered plants include Arizona, Colorado, California, and Virginia. Investments in new gas plants will become more risky if some form of carbon dioxide emissions price is enacted in the next few years.

- February 11, 2019 – The mayor of Los Angeles announced that the city will close rather than modernize three gas-fired power plants after the California legislature passed a bill requiring the state to get 100 percent of its electrical power from climate-friendly sources by 2045. Instead, the city will pursue clean energy technologies with battery storage. The Scattergood, Haynes, and Harbor natural gas plants will be phased out by 2029.[2227] In a press statement, Los Angeles mayor Eric Garcetti said, "This is the beginning of the end of natural gas in Los Angeles. The climate crisis demands that we move more quickly to end dependence on fossil fuel, and that's what today is all about."[2228]

- February 8, 2019 – The Arizona Corporation Commission voted to extend the state moratorium on buying or building new gas-fired power plants and called for energy storage to provide peak power rather than additional natural gas plants.[2229]

- April 1, 2018 – Integrating environmental, economic, and social factors to evaluate overall sustainability, a British team compared shale gas with other electricity options in the United Kingdom. Fracking emerged as one of the least sustainable ways to produce electricity. Specifically, shale gas ranked seventh out of nine options for electrical generation, with wind and solar energy scoring the best and coal the worst. These results

[2225] Elizabeth Weise, "As Earth Faces Climate Catastrophe, US Set to Open Nearly 200 Power Plants," *USA Today*, September 9, 2019, https://www.usatoday.com/story/news/2019/09/09/climate-change-threatens-earth-us-open-nearly-200-power-plants/2155631001/.
[2226] Jared Anderson, "Climate Policy, Economics Give Renewables a Leg up on Natural Gas in the US: WRI," *S&P Global*, July 8, 2019, https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/070819-climate-policy-economics-give-renewables-a-leg-up-on-natural-gas-in-the-us-wri.
[2227] Associated Press, "Mayor: LA Will Ditch Plan to Rebuild Natural Gas Plants," *US News & World Report*, February 11, 2019, //www.usnews.com/news/best-states/california/articles/2019-02-11/mayor-la-will-ditch-plan-to-invest-billions-in-fossil-fuels.
[2228] Nichola Groom, "Los Angeles Abandons New Natural Gas Plants in Favor of Renewables," *Reuters*, February 12, 2019, sec. Commodities, https://www.reuters.com/article/us-usa-california-natgas-idUSKCN1Q12C9.
[2229] David Wichner, "Regulators Extend Ban on New Gas Power Plants in Arizona," *Arizona Daily Star*, February 8, 2019, https://tucson.com/business/regulators-extend-ban-on-new-gas-power-plants-in-arizona/article_5d492ca0-5763-5fe5-8eac-29f63cbe2b72.html.

suggest that "a future electricity mix … would be more sustainable with a lower rather than a higher share of shale gas."[2230, 2231]

- July 14, 2017 – A European team evaluated the performance of coal- and gas-fired power plants that are used to back up renewable energy as the European Union transitions to greater reliance renewable sources for electrical generation. As renewables increasingly dominate, traditional fossil fuel plants will be required to ramp up and down and cycle on and off more frequently, However, these ramping and cycling events will negatively impact the operation of the fossil fuel power plants, as they will become fatigued, resulting in higher operational and maintenance costs, reduced lifetime, degraded performance, and higher emissions of air pollution over time. Gas plants are generally more efficient, faster, and less polluting than coal, but under certain conditions will produce more nitrogen oxides (a component of smog) and more carbon monoxide than coal-fired plants. Current fossil fuel technology will need significant and costly improvements in order to handle the increased gradients, number of starts, lower minimum load and emissions.[2232]

- February 1, 2017 – There is a high degree of uncertainty about the methane emissions from natural gas-fired power plants. As part of a study that also included oil refineries, a Purdue University team evaluated methane emissions from three gas-fired power plants in Utah, Indiana, and Illinois during hours of peak operation. Both fugitive methane leaks from the facility at large as well as uncombusted methane from the stacks were measured using aircraft. Results showed that average methane emission rates were larger than facility-reported estimates by factors of 21-120. The authors concluded that gas-fired power plants "may be significant contributors to annual methane emissions in the U.S. despite lack of facility emission reporting in U.S. inventories. Futhermore, results suggest that the primary source of methane emissions at these facilities may be from noncombustion sources."[2233]

- June 28, 2015 – Pregnant women living near gas-fired power plants were more likely to give birth prematurely, according to a study of more than 400,000 infants born in Florida between 2004 and 2005. This study investigated associations between adverse birth outcomes and residential proximity to several types of power plants, including those burning oil, gas, and solid waste.[2234]

[2230] Jasmin Cooper, Laurence Stamford, and Adisa Azapagic, "Sustainability of UK Shale Gas in Comparison with Other Electricity Options: Current Situation and Future Scenarios," *Science of The Total Environment* 619–620 (April 2018): 804–14, https://doi.org/10.1016/j.scitotenv.2017.11.140.

[2231] Josh Gabbatiss, "Scientists Find Fracking Is One of the Least Sustainable Ways to Produce Electricity," *The Independent*, January 16, 2018, sec. Climate, https://www.independent.co.uk/climate-change/news/fracking-electricity-production-energy-shale-gas-extraction-sustainable-a8160661.html.

[2232] Miguel Angel Gonzalez-Salazar, Trevor Kirsten, and Lubos Prchlik, "Review of the Operational Flexibility and Emissions of Gas- and Coal-Fired Power Plants in a Future with Growing Renewables," *Renewable and Sustainable Energy Reviews* 82 (2018): 1497–1513, https://doi.org/10.1016/j.rser.2017.05.278.

[2233] Tegan N. Lavoie et al., "Assessing the Methane Emissions from Natural Gas-Fired Power Plants and Oil Refineries," *Environmental Science & Technology* 51, no. 6 (2017): 3373–81, https://doi.org/10.1021/acs.est.6b05531.

[2234] Sandie Ha et al., "Associations Between Residential Proximity to Power Plants and Adverse Birth Outcomes," *American Journal of Epidemiology* 182, no. 3 (2015): 215–24, https://doi.org/10.1093/aje/kwv042.

- September 22, 2012 – An investigation of methane and nitrous oxide emissions at eight different gas-fired power plants in Korea found that emissions can vary depending on combustion technologies. Results from this study differed both from those used as default emission rates by the Intergovernmental Panel on Climate Change and from those measured in Japan. The authors concluded that technology-specific and country-specific emission factors for gas-fired power plants need to be established.[2235]

- February 27, 2012 – Using hospitalization data, a research team working in New York State examined whether living near a fuel-fired power plant increased the rate of hospitalization for asthma, acute respiratory infections, and chronic obstructive pulmonary disease, all of which have known links to air pollution exposure. Preliminary analyses of hospitalization rates associated with a residence in a zip code with a power plant stratified by type of fuel used (coal, gas, oil, or solid waste) did not show clear or consistent patterns. Therefore, patients were classified as exposed if they lived in a zip code with at least one power plant in it regardless of the type of fuel used. After adjusting for age, sex, race, median household income, and rural/urban residence, the research team found significantly elevated rates of hospitalization for asthma (11 percent increase), acute respiratory infection (15 percent increase), and chronic obstructive pulmonary disease (17 percent increase) among New Yorkers living near at least one fuel-fired power plant.[2236]

- October 20, 2011 – Emergency room visits and hospital admissions in elderly people living close to a new gas-fired power plant in Italy were counted and related to levels of air pollution both before and after the plants became operational. The results showed that ambient levels of nitrogen oxides and particulate matter rose after the plant started operations. Further, despite the fact that pollutants were below the limits set by the European legislation, there was a positive correlation between number of emergency room visits and daily concentrations of these air pollutants among nearby residents aged 70 or older.[2237]

- April 5, 2010 – Most new fossil fuel power plants are gas-powered. In this study, a research team estimated the number of premature deaths from fine particulate matter that would result from bringing 29 proposed fossil-fuel power plants in Virginia on line. Their modelling predicted that, were all 29 plants made operational, concentrations of fine particulate air pollution would rise in 271 counties across 19 states. Over a six-year

[2235] Seehyung Lee et al., "A Study on the Evaluations of Emission Factors and Uncertainty Ranges for Methane and Nitrous Oxide from Combined-Cycle Power Plant in Korea," *Environmental Science and Pollution Research* 20, no. 1 (2013): 461–68, https://doi.org/10.1007/s11356-012-1144-1.
[2236] Xiaopeng Liu, Lawrence Lessner, and David O. Carpenter, "Association between Residential Proximity to Fuel-Fired Power Plants and Hospitalization Rate for Respiratory Diseases," *Environmental Health Perspectives* 120, no. 6 (2012): 807–10, https://doi.org/10.1289/ehp.1104146.
[2237] Agostino Di Ciaula, "Emergency Visits and Hospital Admissions in Aged People Living Close to a Gas-Fired Power Plant," *European Journal of Internal Medicine* 23, no. 2 (2012): e53–58, https://doi.org/10.1016/j.ejim.2011.09.013.

period, 104 cumulative excess deaths would occur due to operations of these proposed plants.[2238]

Gas-fired residential appliances

Gas flames burning inside of homes and buildings represent the terminus of the fracking pipeline and are a significant contributor to poor indoor air quality. Gas-fired appliances create several pollutants including corrosive nitrogen dioxides, deadly carbon monoxide (CO), and the carcinogens formaldehyde and benzene, for which there are no safe levels of exposure. They also inevitably leak methane. Gas stoves, whose emissions are not routinely vented to the outside worlds—as are furnaces, boilers and water heaters—represent a special risk. Nearly three-quarters of methane emissions from gas stoves take place while the stove is turned off and not in use. At the same time levels of hazardous air pollutants from everyday use of gas stoves often exceed the limits of outdoor air quality standards. Indoor concentrations are often much higher than health-protective guidelines set by the World Health Organization. Recent research strongly recommends complete elimination of gas stoves as even opening windows or running mechanical ventilation, while critical, is often not adequate in reducing gas stove pollution to safe levels. Gas stoves represent a significant exposure source to both benzene, which is created within the gas flame as a combustion byproduct, and nitrogen dioxide, which is created when the high heat generated by methane combustion cause nitrogen and oxygen in the air to combine. According to the U.S. EPA, the air inside homes with gas stoves has average concentrations of nitrogen dioxide that are 50-400 percent higher than the air inside homes with electric stoves. Nitrogen dioxide exposure is a proven cause of childhood asthma. A 2013 study found that children living in a home with a gas stove have a 42 percent increased risk of current asthma and a 24 percent increased risk of lifetime asthma. A 2022 investigation that built on this earlier research found that 13 percent of childhood asthma cases in the United States are attributable to the use of gas stoves. Recognizing that cooking with a gas stove increases household air pollution and the risk of childhood asthma, the American Medical Association has called for a transition from gas stoves to electric stoves in an equitable manner.

- March 3, 2023 – A group of public health researchers reviewed the evidence on the link between gas stoves and adverse health effects and advised that households inhabited by individuals with asthma, chronic obstructive pulmonary disease, or other respiratory diseases should, if feasible, make the transition to electric stoves, "and all other households could consider it." The group also noted that there also exists a strong climate rationale to electrify home appliances and ban natural gas hookups in new residential construction.[2239]

[2238] Richard P. Hermann, Frank Divita, and Jack O. Lanier, "Predicting Premature Mortality from New Power Plant Development in Virginia," *Archives of Environmental Health: An International Journal* 59, no. 10 (2004): 529–35, https://doi.org/10.1080/00039890409605170.
[2239] John R. Balmes et al., "Cooking with Natural Gas: Just the Facts, Please," *American Journal of Respiratory and Critical Care Medicine* 207, no. 8 (April 15, 2023): 996–97, https://doi.org/10.1164/rccm.202302-0278VP.

- January 21, 2023 – Using the annual Munich Oktoberfest as a case study, an international research team documented significant methane leaks from gas-fired cooking and heating appliances and showed that electricity for cooking and heating has been a more climate-friendly energy source at the festival since 2005 due to the increasing use of renewable electricity. The team's air monitoring results showed that Oktoberfest could reduce total carbon emissions from energy consumption by 87 percent if all gas-fired appliances were replaced with electric ones. Methane emissions from gas-fired heaters and grills originate both from leaks and from incomplete combustion. Extending the study to 25 major natural gas-consuming nations, the team determined that natural gas still generates lower carbon emissions for residential appliances than electricity in 18 of 25 countries studied due to high numbers of coal-burning power plants. However, "as the share of renewable energy in the electricity mix steadily increases…the carbon footprint of electricity will be lower than that of natural gas in these countries in the near future." In other words, the climate friendliness of electric residential appliances over gas-fired appliance will increase over time.[2240]

- January 19, 2023 – An assessment of the barriers that prevent a rapid transition to induction and electric stoves identified the need of many residents living in low-income, substandard housing to rely on gas stoves for space heating as an obstacle to electrification. Public efforts toward building electrification "must center equity and improving housing conditions for disadvantaged groups, especially those who disproportionately rely on stoves as a supplemental heating source."[2241]

- December 21, 2022 – An international team of researchers found that gas stoves are responsible for almost 13 percent of childhood asthma in the United States. Using data from the American Housing Survey on gas stove use in U.S. homes, the team quantified the populational attributable fraction for gas stove use and current childhood asthma. This epidemiological tool describes the fraction of a disease that could theoretically be prevented if exposure to a given risk factor were eliminated. Specifically, team found that 12.7 percent of current childhood asthma in the United States could be prevented if gas stoves were not present. The population attributable factor varied greatly by state. For Illinois, 21.1 percent of childhood asthma cases were attributable to gas stoves. In California, 20.1 percent. In New York, 18.8 percent. In Massachusetts, 15.4 percent. In Pennsylvania, 13.5 percent. Florida experienced the lowest burden at 3 percent. Differences between states, the authors point out, are entirely due to different state-level proportions of households that cook with gas. In Illinois, for example, nearly 80 percent of households with children cook with gas, whereas only 9 percent of households in Florida do.[2242]

[2240] Florian Dietrich et al., "Climate Impact Comparison of Electric and Gas-Powered End-User Appliances," *Earth's Future* 11, no. 2 (February 2023), https://doi.org/10.1029/2022EF002877.
[2241] Misbath Daouda et al., "Correspondence on 'Home Is Where the Pipeline Ends: Characterization of Volatile Organic Compounds Present in Natural Gas at the Point of the Residential End User,'" *Environmental Science & Technology* 57, no. 4 (January 31, 2023): 1848–49, https://doi.org/10.1021/acs.est.2c09423.
[2242] Talor Gruenwald et al., "Population Attributable Fraction of Gas Stoves and Childhood Asthma in the United States," *International Journal of Environmental Research and Public Health* 20, no. 1 (December 21, 2022): 75, https://doi.org/10.3390/ijerph20010075.

- November 8, 2022 – In a review of the data linking nitrogen dioxide from gas stoves to health harms, the American Public Health Association (APHA) called, in a policy statement, for the U.S. EPA, the U.S. Department of Housing and Urban Development, and the U.S. Centers for Disease Control to formerly recognize "the links among gas stove emissions, nitrogen dioxide pollution, and increased risk of illness in children, older adults, people with underlying conditions, and environmental justice communities. Furthermore, the public and health care practitioners should be educated on the health harms of gas stove emissions and promotion of mitigation solutions should be expedited." The APHA further called upon the EPA to set health-protective indoor air quality guidelines, called upon the U.S. Consumer Product Safety Commission to set performance standards for gas stoves and range hoods, and called upon local and state legislative and regulatory bodies "to adopt residential building codes with preferences for installing electric appliances and to require electric appliances for building projects receiving municipal or state funding."[2243]

- June 28, 2022 – A research team led by the Harvard T.H. Chan School of Public Health investigated hazardous air pollutants present in natural gas combusted inside of Massachusetts homes. The team identified 21 different toxic air pollutants, including benzene and toluene, within consumer-grade natural gas entering homes. Undetected leaks were common, and concentrations of hazardous air pollutants in indoor natural gas emissions were highly variable, with the highest concentrations taking place during the winter months. The team noted that hazardous air pollutants from indoor natural gas leaks are not routinely monitored or accounted for in any state or federal inventory. This study is the first to provide a detailed analysis of the hazardous air pollutants present in natural gas used in residential buildings.[2244]

- May 18, 2022 – In a resolution intended to inform physicians and health care providers about the health dangers of gas stoves, the American Medical Association (AMA) recognized the association between the use of gas stoves, indoor nitrogen dioxide levels, and childhood asthma. The resolution also urged advocacy for innovative programs to assist with the cost of transitioning from gas to electric stoves. This resolution passed into AMA policy, thereby committing the professional organization to carrying out such education and advocacy.[2245, 2246]

[2243] American Public Health Association, "Gas Stove Emissions Are a Public Health Concern: Exposure to Indoor Nitrogen Dioxide Increases Risk of Illness in Children, Older Adults, and People with Underlying Health Conditions," Policy Statement, November 8, 2022, https://www.apha.org/Policies-and-Advocacy/Public-Health-Policy-Statements/Policy-Database/2023/01/18/Gas-Stove-Emissions.

[2244] Drew R. Michanowicz et al., "Home Is Where the Pipeline Ends: Characterization of Volatile Organic Compounds Present in Natural Gas at the Point of the Residential End User," *Environmental Science & Technology*, June 28, 2022, acs.est.1c08298, https://doi.org/10.1021/acs.est.1c08298.

[2245] American Medical Association House of Delegates, "Draft Resolution: Informing Physicians, Health Care Providers, and the Public That Cooking with a Gas Stove Increases Household Air Pollution and the Risk of Childhood Asthma," May 18, 2022, https://www.ama-assn.org/system/files/a22-439.pdf.

[2246] American Medical Association, "Informing Physicians, Health Care Providers, and the Public That Cooking with a Gas Stove Increases Household Air Pollution and the Risk of Childhood Asthma D-135.964," 2022, https://policysearch.ama-assn.org/policyfinder/detail/gas%20stove?uri=%2FAMADoc%2Fdirectives.xml-D-135.964.xml.

- January 27, 2022 – A Stanford University study quantified methane leaks from gas-fired stoves and ovens in 53 homes. The results showed that methane was released during all phases of stove use: when it was turned off, when it was in use, and during ignition and extinguishment. The team estimated that between 0.8 and 1.3 percent of the gas used by kitchen stoves is released as unburned methane, with more than three-quarters of emissions taking place when the stove was turned off. "Using a 20-year timeframe for methane, annual methane emissions from all gas stoves in U.S. homes have a climate impact comparable to the annual carbon dioxide emissions of 500,000 cars." In addition, the team found that nitrogen dioxide emissions were linearly related to the amount of gas burned. "Our data suggest that families who don't use their range hoods or who have poor ventilation can surpass the 1-hour national standard of NO2 (100 ppb) within a few minutes of stove usage, particularly in smaller kitchens."[2247]

- May 5, 2020 – A report on the health effects of gas stoves released by a consortium of environmental advocacy groups led by the Rocky Mountain Institute includes a comprehensive compendium of the many dozens of peer-review studies documenting the health harms from gas stove pollution and dating back more than 40 years. All together, these studies show that "gas stoves may be exposing tens of millions of people to levels of air pollution in their homes that would be illegal outdoors under national air quality standards."[2248]

- March 27, 2020 – A research team measured methane emissions from gas-fired appliances at the 2018 Oktoberfest folk festival in Munich, Germany where natural gas is used to heat tents and power grills and other cooking appliances. Taking into account wind speed and direction, the team found enhancements of up to 100 parts per billion, showing that large festivals can be significant methane emitters due to both incomplete combustion and methane leakage from gas appliances.[2249]

- February 4, 2015 – An Oregon State University team used data from the National Health and Nutrition Examination Survey to identify young children living homes with a gas stove and whose parents provided information on their stove habits and data on pneumonia and cough. They found higher risks for pneumonia and cough among children living in homes with gas stoves used for home heating without ventilation.[2250]

- September 2, 2014 – A cross-sectional study that examined the association between gas stoves and chronic respiratory illness in U.S. children found that ventilation is associated

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[2247] Eric D. Lebel et al., "Methane and NOx Emissions from Natural Gas Stoves, Cooktops, and Ovens in Residential Homes," *Environmental Science & Technology* 56, no. 4 (February 15, 2022): 2529–39, https://doi.org/10.1021/acs.est.1c04707.
[2248] Brady Anne Seals and Andee Krasner, "Health Effects from Gas Stove Pollution" (Rocky Mountain Institute, Physicians for Social Responsibility, Mothers Out Front, and Sierra Club, 2020), https://rmi.org/insight/gas-stoves-pollution-health.
[2249] Jia Chen et al., "Methane Emissions from the Munich Oktoberfest," *Atmospheric Chemistry and Physics* 20, no. 6 (March 27, 2020): 3683–96, https://doi.org/10.5194/acp-20-3683-2020.
[2250] Eric S Coker et al., "A Cross Sectional Analysis of Behaviors Related to Operating Gas Stoves and Pneumonia in U.S. Children under the Age of 5," *BMC Public Health* 15, no. 1 (December 2015): 77, https://doi.org/10.1186/s12889-015-1425-y.

with reduction, but not elimination of, childhood asthma risk. The research team found that lung function was higher among children whose parents reported using range hoods when operating gas stoves.[2251]

- January 1, 2014 – A study of indoor air pollution from gas stoves in California homes used a mass-balance model to estimate time-dependent pollutant concentrations and exposures experienced by individual inhabitants. The researchers found that gas stoves are a significant contributor to poor indoor quality and were associated with elevated levels of nitrogen dioxide, carbon monoxide, and formaldehyde. The simulation model estimated that—in homes using gas stove without coincident use of venting range hoods—62 percent, 9 percent, and 53 percent of occupants were routinely exposed to levels of nitrogen dioxide, carbon monoxide, and formaldehyde that exceeded acute health-based standards and guidelines.[2252]

- August 20, 2013 – A meta-analysis of 41 studies on the link between indoor nitrogen oxides from exposure to gas cooking and asthma in children provided "quantitative evidence that, in children, gas cooking increases the risk of asthma and indoor NO2 increases the risk of current wheeze." The findings showed that children living in homes with gas stoves have a 42 percent increased risk of having current asthma and a 24 percent increased risk of developing asthma during their lifetime.[2253]

[2251] Molly L Kile et al., "A Cross-Sectional Study of the Association between Ventilation of Gas Stoves and Chronic Respiratory Illness in U.S. Children Enrolled in NHANESIII," *Environmental Health* 13, no. 1 (December 2014): 71, https://doi.org/10.1186/1476-069X-13-71.
[2252] Jennifer M. Logue et al., "Pollutant Exposures from Natural Gas Cooking Burners: A Simulation-Based Assessment for Southern California," *Environmental Health Perspectives* 122, no. 1 (January 2014): 43–50, https://doi.org/10.1289/ehp.1306673.
[2253] Weiwei Lin, Bert Brunekreef, and Ulrike Gehring, "Meta-Analysis of the Effects of Indoor Nitrogen Dioxide and Gas Cooking on Asthma and Wheeze in Children," *International Journal of Epidemiology* 42, no. 6 (December 1, 2013): 1724–37, https://doi.org/10.1093/ije/dyt150.

Inaccurate jobs claims, increased crime rates, threats to property values and mortgages, and local government burden

According to multiple studies in multiple states, the oil and gas industry's promises of job creation from drilling for natural gas have been greatly exaggerated. Many of the jobs are short-lived, have gone to out-of-area workers, and, increasingly, are lost to automation. The contraction of the industry in 2019 and 2020, accelerated by the coronavirus pandemic, led to mass lay-offs, lost jobs and high unemployment among fracking crews and associated workers. Many of these jobs failed to rebound.

With the arrival of drilling and fracking operations, rural communities have consistently experienced steep increases in rates of crime, variously including murder, assault, rape, sex trafficking, larceny, robbery, burglary, embezzlement and auto theft. Indigenous women are disproportionately victimized by violent crimes associated with oil and gas activities. In the Marcellus Shale region, violent crime increased 30 percent in counties that experienced a fracking boom compared to those without fracking. Aggravated and sexual assaults were the crimes primarily responsible for this increase. Crime rates have increased even with additional allocation of funds for public safety. Bust cycles are associated with upticks in poverty, unemployment, addiction, and erosion of social norms.

Financial and other strains on municipal services include those on law enforcement, road maintenance, emergency services, and public school district administration. In shale boom areas, school districts suffer lower test scores, lower attendance, higher teacher turnover, and exacerbated education inequities. Economists are increasingly quantifying community quality of life impacts and the unequal distribution of costs and benefits associated with drilling and fracking.

Drilling and fracking pose an inherent conflict with mortgages and property insurance due to the hazardous materials used and the associated risks. With the departure of drilling and fracking operations from these communities, some of the challenges are eased. However, such departures can also lead to additional economic harms, such as by sharp upticks in foreclosures, late car and mortgage payments, empty housing units, and failed or diminished local businesses. In Oklahoma and in England, fracking-induced earthquakes have negatively affected property values.

- December 1, 2022 – Holders of Pennsylvania's Marcellus shale oil and gas leases who have higher incomes or are from more socially organized communities have the skills or legal resources to negotiate for more favorable conditions in their leases, according to a discussion paper developed for the National Bureau of Economic Research. Findings include a positive association between royalty rates and environmentally protective clauses, as well as royalty rates and increasing prevalence of the most environmentally protective clauses over time. This pattern suggests that those who are able to delay signing leases gain better conditions. The researchers identify a "distributive environmental justice concern, such as those previously documented in a small oil and

gas leasing literature," whereby "wealth, race, ethnicity, and language affect the prevalence of beneficial lease clauses."[2254]

- November 28, 2022 – An *Energy News Network* investigation identified four reasons why seven of the state's Appalachian counties still have unemployment rates that exceed the state average despite promised jobs accompanying the decade-long Ohio shale gas boom. These include the short-term and itinerant nature of oil and gas jobs; the existence of fracking-related jobs in metropolitan areas rather than in the shale fields of Appalachia; limited infrastructure in oil and gas counties, which has led to less shale development; and the fact that some oil and gas jobs were taken by workers displaced from the coal industry.[2255]

- October 13, 2022 – An interdisciplinary review finds that fracking's boom-bust cycles bring unique impacts to communities, and that, while boom impacts are well studied, "there is a persistent dearth of research on… impacts during busts." The bust studies they did identify found impacts such as abandoned or idled oil and gas wells carrying risks to communities; economic impacts such as rising unemployment and upticks in poverty; decommissioned, vacant, or otherwise unused oil and gas infrastructure creating debt and maintenance challenges; increases in addiction and gender-based violence; stressed public services; and "social capital" impacts such as mental health issues and the "continued erosion of social norms and community culture" that began during boom times. The researchers identify opportunities for local governmental intervention, such as exercising leverage they may have in well permitting, and in disclosure requirements with regard to chemicals and processes. The latter may assist medical practitioners to respond to public health needs and researchers to fill knowledge gaps. The authors encourage governments to be more proactive overall on community impacts.[2256]

- July 8, 2021 – Citing a "transition towards a more renewable future" and an all-time low of only ten registered students over the previous two years, the University of Calgary in Canada suspended admission to its oil and gas engineering bachelor program.[2257]

- July 2, 2021 – Federal Reserve Bank of Dallas researchers found that the region's oil and gas industry employed fewer people by 2020 than at the beginning of the fracking boom eleven years ago, even as production quadrupled. Due to technological "efficiencies," Texas and New Mexico production rose 14 percent from December 2014 and December

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[2254] Max Harleman, Pramod Manohar, and Elaine L Hill, "Negotiations of Oil and Gas Auxiliary Lease Clauses: Evidence for Pennsylvania's Marcellus Shale," Working Paper, NBER Working Paper Series (National Bureau of Economic Research, December 2022), https://www.nber.org/papers/w30806.
[2255] Kathiann M. Kowalski, "Why Ohio's Top Oil and Gas Producing Counties Continue to Lag in Jobs," *Energy News Network*, November 28, 2022, https://energynews.us/2022/11/28/why-ohios-top-oil-and-gas-producing-counties-continue-to-lag-in-jobs/.
[2256] Meghan Klasic et al., "A Review of Community Impacts of Boom-Bust Cycles in Unconventional Oil and Gas Development," *Energy Research & Social Science* 93 (November 2022): 102843, https://doi.org/10.1016/j.erss.2022.102843.
[2257] Mark Villani, "University of Calgary Suspends Admission for Oil and Gas Engineering Program," *CTV News*, July 8, 2021, https://calgary.ctvnews.ca/mobile/university-of-calgary-suspends-admission-for-oil-and-gas-engineering-program-1.5502133.

2017 while industry employment dropped 29 percent during that time. The pandemic led to further job cuts and though recovery may add jobs, companies will "require fewer employees for more output."[2258]

- July 1, 2021 – Writing in the *MIT Technology Review*, environmental sociologist Colin Jerolmack reviewed the shaky financial ground on which the Appalachian fracking boom was based and provided a realistic view of actual fracking employment trends. He wrote, "Fracking has always been expensive; extraordinarily generous fossil-fuel subsidies helped hide the true cost." The oil and gas industry eliminated more than 100,000 jobs in 2020, and 70 percent of those may not ever return. In April 2021, the economic sector within which oil and gas jobs are tracked, the mining sector, had the highest US unemployment rate.[2259]

- June 17, 2021 – Economists determined that fracking booms in Arkansas, North Dakota, and West Virginia were associated with more crime than comparison states, and these crimes carried an estimated $15.68 million (in 2008 dollars) "annual victimization cost" per state. The methods used to estimate these costs was based on an established methodology on the cost of crimes to society. The comparison states had similar crime rates to the fracking states before the boom. The data from multiples sources used in the study covered the years 2000 to 2015. Crimes linked with fracking in the study were murder, forcible rape, robbery, aggravated assault, burglary, and embezzlement. Breaking these down by the instances and costs of specific crimes, this research showed that the 1.3 more murders per 100,000 residents led to a cost of $11.63 million, and the three additional forcible rapes per 100,000 averaged $7.45 million. The fracking boom states had 27.53 more aggravated assaults, costing about an extra $2.94 million. Researchers said their "consistent and robust results… support the hypothesis that the shale boom increases crime for relatively rural American states, especially violent crime."[2260]

- June 4, 2021 – The Enbridge Line 3 pipeline project brought an influx of thousands of workers to Minnesota "who are staying in hotels, campgrounds and rental housing along the pipeline route, often in small towns like Thief River Falls, and on or near Native reservations." The Violence Intervention Project in Thief River Falls received "more than 40 reports about Line 3 workers harassing and assaulting women and girls who live in north-western Minnesota." In addition, two workers charged in a sex trafficking sting operation were Line 3 workers from Missouri and Texas, employed by the Enbridge subcontractor Precision Pipeline. Violence prevention advocates had warned state officials in advance of the project "of the proven link between employees working in extractive industries and increased sexual violence." Indeed, Minnesota's Public Utilities Commission acknowledged in its environmental impact statement that the likelihood of

[2258] Carolyn Davis, "Permian Oil Patch Faces Economic Conundrum as Efficiencies Reduce Workforce," Natural Gas Intelligence, July 2, 2021, https://www.naturalgasintel.com/permian-oil-patch-faces-economic-conundrum-as-efficiencies-reduce-workforce/.
[2259] Colin Jerolmack, "The Fracking Boom Is Over. Where Did All the Jobs Go?," *MIT Technology Review*, July 1, 2021, https://www.technologyreview.com/2021/07/01/1027822/fracking-boom-jobs-industry/.
[2260] Shishir Shakya and Kazi Sohag, "The Fracking Boom and Crime Rates in Rural American States: Some Critical Insights," *The Extractive Industries and Society* 8, no. 3 (2021), https://doi.org/10.1016/j.exis.2021.100948.

sex trafficking or sexual abuse would increase if Line 3 were permitted and that the affected regions do not have the resources to track and prevent this violence.[2261]

- June 4, 2021 – Economists found that lower-income census tracts in Oklahoma experienced disproportionately greater negative impacts on property values from "induced" earthquakes compared to higher-income areas. Scientists attribute the dramatic increase in earthquakes in Oklahoma after 2009 to the disposal of fracking wastewater into deep injection wells. Most of these range in magnitude from 3 to 4—strong enough to be felt, though rarely causing property damage—but 30 of the 850 earthquakes in 2015 were magnitude 4 or greater. These induced earthquakes may negatively impact property values through the physical damage they cause. This study added to the literature on fracking and property values by using a unique dataset, US Geological Survey's Did You Feel It? system, by extending into the years following implementation of Oklahoma's wastewater injection rules that decreased induced earthquakes, and by addressing the environmental justice dimension, motivated by the body of research indicating lower-income groups suffer disproportionate harm from natural disasters. This study confirmed that earthquakes negatively impact the pricing of housing, including negative impacts linked with each additional earthquake in 2012, 2013, and 2014. Not only did the researchers find that lower-income households saw disproportionate impacts, but these impacts also lasted longer. The researchers "posit that poorer households incur greater proportional damage for any relative seismic event due to lower quality construction of their properties," and that these households may not be able to repair their properties in a timely way following an earthquake. Overall, the pricing impacts began to lessen in 2016 coinciding with the law mandating a reduction in induced seismic activity.[2262]

- April 26, 2021 – Pennsylvania "has an opportunity to manage the decline of its polluting energy industry while investing in sustainable, high-paying green union jobs as a replacement," according to the *Philadelphia Inquirer* Editorial Board. The Board criticized the state's continued investment in natural gas infrastructure in light of climate concerns and the failure of the industry to provide a remedy for the previous, unmanaged decline of coal and steel jobs. Citing statistics on increasing employment for solar installers and wind power technicians, the Board recommended that Pennsylvania transition fossil fuel subsidies into green jobs and called for investment in communities now shedding fracking jobs as well as in black communities that have suffered the most harm from oil and gas pollution.[2263]

- March 31, 2021 –Colorado regulations now require a minimum 2,000-foot setback between oil and gas sites and homes. However, residents living near proposed fracking sites that were approved before the law went into effect are not protected by this rule.

[2261] Hilary Beaumont, "Sexual Violence Along Pipeline Route Follows Indigenous Women's Warnings," *The Guardian*, June 4, 2021, https://www.theguardian.com/us-news/2021/jun/04/minnesota-pipeline-line-3-sexual-women-violence.
[2262] Chris Mothorpe and David Wyman, "What the Frack? The Impact of Seismic Activity on Residential Property Values," *Journal of Housing Research* 30, no. 1 (2021): 34–58, https://doi.org/10.1080/10527001.2020.1827579.
[2263] Editorial Board, "Fracking Jobs Will Disappear. Pennsylvania Has to Manage the Decline.," *Philadelphia Inquirer*, April 26, 2021, https://www.inquirer.com/opinion/editorials/fracking-biden-climate-greenhouse-gas-methane-pennsylvania-20210426.html.

New homeowners in Colliers Hill, a suburban development in Erie, found themselves just 940 feet from a well pad. As reported by the *Colorado Sun,* this Occidental Petroleum Corporation fracking operation is exempt from the setback rule, as are 200 drilled but uncompleted wells and nearly 1,600 drilling permits that had been approved in the state in the twelve months before new rules went into effect. Colliers Hill residents began demanding action from the Erie Board of Trustees and filing complaints with the state. Erie Mayor Jennifer Carroll "told them that there was little the town could do, even though it had adopted its own stringent oil and gas rules, because the road separating Colliers Hills from the wells was also the boundary between Erie and unincorporated and pro-oil development Weld County."[2264]

- March 29, 2021 – At least 20 percent of jobs in oil and gas drilling, operational support, and maintenance may be automated in the next 10 years, reported the *Houston Chronicle*. Robotics and automation will replace hundreds of thousands of oil and gas industry jobs, in addition to those lost in the pandemic. In addition to inspection, maintenance, and repairs, the industry expects robotics to "reduce the number of roughnecks required on a drilling rig by 20 to 30 percent."[2265]

- March 8, 2021 – Greene County, a Pennsylvania fracking boom region with 1,257 gas wells, may not be able to cover its costs by 2023, despite receiving $37.2 million in gas development-related impact fees over ten years as part of a state program. Newly elected Green County commissioners criticized previous impact fee expenditures as "shortsighted and wasteful" and resolved to stop using these funds to balance the budget each year, according to an investigation by *Spotlight PA*. The new commissioners said that the county never planned appropriately for the transition from the coal bust and is now paying the price as the fracking bust arrives. The county's hospitality and rental markets had expanded dramatically to accommodate temporary, out-of-town gas company workers. Now many fewer such workers are spending money on rent, hotels, and elsewhere in the local economy. Public records showed that the county spent no income from the impact fees on planning initiatives, tax reductions, water preservation, or career and technical centers.[2266]

- March 8, 2021 – The Violence Intervention Project in Thief River Falls, Minnesota experienced an increase in calls for their services since the Enbridge Line 3 pipeline construction began in December 2020. The Violence Intervention Project described the assaults experienced by their callers, as well as other instances of harassment at local businesses, in a request for reimbursement from Enbridge's public safety fund, obtained through a public records request by the *Minnesota Reformer.* State permits for Enbridge

[2264] Mark Jaffe, "This Erie Neighborhood Is Ground Zero for Colorado's Collision of Fracking and Housing," *The Colorado Sun*, March 31, 2021, https://coloradosun.com/2021/03/31/colliers-hill-erie-colorado-oxy-fracking-conflict/.
[2265] Marcy de Luna, "Robots Could Replace Hundreds of Thousands of Oil and Gas Jobs by 2030," *Houston Chronicle*, March 29, 2021, https://www.houstonchronicle.com/business/energy/article/Robots-could-replace-hundreds-of-thousands-of-oil-16061352.php.
[2266] Jamie Martines, "A Pennsylvania County Went from Bust to Boom Times with Natural Gas. Now, It's Nearly Broke.," *Spotlight PA*, March 8, 2021, https://www.spotlightpa.org/news/2021/03/pa-greene-county-broke-tax-increase-gas-payouts-businesses/.

Line 3 pipeline construction had required that the company create this fund to cover expected additional law enforcement costs as well as the human trafficking prevention plan linked with the project. The Violence Intervention Project's request—seeking reimbursement for hotel room costs for victims when its emergency shelter was full—said that finding hotel rooms has been increasingly difficult as pipeline workers occupy them, and that the cost of hotel rooms had doubled in recent months.[2267]

- February 24, 2021 – Contractors on Enbridge's Line 3 pipeline were arrested and charged in a human trafficking sting in Itasca County, Minnesota. The two men, out-of-state workers, were among seven arrested. One was charged with carrying a pistol without a permit and one count of solicitation to engage in prostitution and the other with one count of solicitation of a person believed to be a minor.[2268]

- February 18, 2021 – A policy researcher identified 23 locations in the US that have the highest rates of Missing and Murdered Indigenous Women (MMIW) cases. Within these, the researcher pinpointed 16 "hot spots," and of these, six were within 25 miles of drilling and fracking sites, and three more within 25 to 50 miles. The researcher wrote that this "analysis of the locations of fracking and other resource extraction sites in relation to the MMIW 'hot spots' highlights a need for additional research into the possible correlation of these two factors." The paper reviews the evidence showing that "man camps" change the demographics of communities near fracking "and have been connected to increased rates of violence, sexual assault, sexually transmitted diseases, prostitution, sex trafficking, and an increased presence of illicit drugs."[2269]

- February 12, 2021 – A study published by the Ohio River Valley Institute, a non-profit research center, found that jobs, personal income, and population all declined between 2008 and 2019 in the 22 Ohio, Pennsylvania, and West Virginia counties that produce 90 percent of Appalachia's natural gas. The seven eastern Ohio counties that suffered the worst impacts experienced a net job loss of more than eight percent. In addition, money that had been expected to stay in communities was spent outside the region, and, because counties were counting on job creation by oil and gas companies, they had given tax breaks and other incentives that reduced the amount of revenue they received.[2270, 2271]

[2267] Rilyn Eischens, "Shelter Reports Assaults, Harassment Linked to Line 3 Pipeline Workers," *Minnesota Reformer*, March 8, 2021, https://minnesotareformer.com/2021/03/08/shelter-reports-assaults-harassment-linked-to-line-3-pipeline-workers/.
[2268] Kevin Jacobsen, "2 Arrested in Itasca Co. Human Trafficking Bust Were Line 3 Workers," cbs3duluth.com, February 24, 2021, https://cbs3duluth.com/2021/02/24/2-arrested-in-itasca-co-human-trafficking-bust-were-line-3-workers/.
[2269] A. Skylar Joseph, "A Modern Trail of Tears: The Missing and Murdered Indigenous Women (MMIW) Crisis in the US," *Journal of Forensic and Legal Medicine* 79 (2021), https://doi.org/10.1016/j.jflm.2021.102136.
[2270] Sean O'Leary, "Appalachia's Natural Gas Counties: Contributing More to the U.S. Economy and Getting Less in Return" (Ohio River Valley Institute, February 2021), https://ohiorivervalleyinstitute.org/wp-content/uploads/2021/02/Frackalachia-Report-update-2_12_01.pdf.
[2271] Beth Harvilla, "Report: Ohio Fracking Counties Saw Declines in Jobs, Population and Income," *The Columbus Dispatch*, February 10, 2021, https://www.thisweeknews.com/story/business/2021/02/10/ohio-fracking-boom-never-translated-more-jobs-and-growth-report-says/4450698001/.

- January 29, 2021 – An investigation by the Pittsburgh *Post-Gazette* predicted that Pennsylvania counties, municipalities, state agencies, and conservation initiatives will have a difficult time making up for the expected record low impact fees to be collected. Based on natural gas prices and wells drilled, total impact fees assessed on the state's shale gas wells were predicted to fall by $56 million, to a record low of $145 million. Lower gas prices also mean lower royalties for landowners who lease land for fracking, including the state itself. The state doubled fracking permit prices in August 2020 but was receiving far fewer applications than anticipated in the fiscal year of this investigation. Because the Department of Environmental Conservation's Office of Oil and Gas Management is funded largely by well-drilling application fees, the Office was struggling to maintain its level of staffing and inspection responsibilities and could be short $17.5 million for the year.[2272]

- December 22, 2020 – UK researchers determined that earthquakes caused by fracking a first exploratory well in the Lancashire area of England led to a 3.9 to 4.7 percent housing price decrease in the region where the earthquakes occurred. Notably, no commercial fracking had yet taken place. This study specifically focused on the effects of issuing licenses that served as an official signal of potential fracking development. The results showed that the licensing itself did not affect housing prices, but when the exploratory fracking triggered small earthquakes, although they did not cause property damage, housing prices fell.[2273]

- July 30, 2020 – Oil and gas production employment in the state was expected to fall to its lowest since 2005, according to Texas Alliance of Energy Producers, which represents 2,600 independent oil and gas producers.[2274] Texas had already lost 46,100 jobs in production and oil-field services from February to June 2020, related to dropped demand during the coronavirus pandemic. The alliance noted that the oil and gas industry was contracting well before the pandemic.

- July 8, 2020 – When considered in aggregate, 25 relevant, quantitative studies all published between 2005 and 2019 provide clear evidence that U.S. drilling and fracking is linked to an increase in crime, according to a systematic review by a social scientist and legal scholar.[2275] A majority of studies found "that shale gas development increases total crime, violent crime, property crime, social disorganization crimes and violence against women." Of seventeen studies that addressed violent crime, none showed that shale gas development led to less violent crime. Of the seven studies addressing shale gas

[2272] Laura Legere, "Pain of Natural Gas Price Drop Spreads to Pa. Agencies, Communities," January 29, 2021, https://www.post-gazette.com/business/powersource/2021/01/29/natural-gas-price-royalties-shale-permits-impact-fees-Pennsylvania-DEP-DCNR/stories/202101280165.
[2273] Stephen Gibbons, Stephan Heblich, and Christopher Timmins, "Market Tremors: Shale Gas Exploration, Earthquakes, and Their Impact on House Prices," *Journal of Urban Economics* 122 (2021), https://doi.org/10.1016/j.jue.2020.103313.
[2274] Paul Takahashi, "Oil and Gas Production Jobs in Texas Could Hit Bottom This Fall," *Houston Chronicle*, July 30, 2020, sec. Energy, https://www.houstonchronicle.com/business/energy/article/Oil-and-gas-employment-forecast-to-bottom-out-15446433.php.
[2275] Paul Stretesky and Philipp Grimmer, "Shale Gas Development and Crime: A Review of the Literature," *The Extractive Industries and Society* 7, no. 3 (2020): 1147–57, https://doi.org/10.1016/j.exis.2020.06.008.

development and crime against women, five of them showed a positive link, one suggested mixed results, and one suggested there no relationship. Of those studies that included data on pre- and post- increases in shale gas production, the review found drilling and fracking leads to a 28 to 46 percent increase in crime in surrounding communities. Only one study addressed shale gas development and crime outside of the United States. Noting the "considerable consistency" in these findings, the researchers recommended that, in addition to environmental impacts, the shale gas-crime considerations "should be considered by policymakers and planners when determining whether and how shale development should be allowed."

- May 26, 2020 – In April 2020, the oil and gas industry cut a record-breaking 26,300 jobs, according to the Texas Workforce Commission. Most of the jobs lost were drilling rig operators, hydraulic fracturing crews and equipment manufacturers.[2276]

- May 11, 2020 – Oil and gas industry journalist Irina Slav examined why young professionals view employment in the oil and gas industry as a poor career choice.[2277] The average age of Society of Petroleum Engineers' members is growing older while the number of students choosing engineering majors linked to careers in oil and gas are dropping. The current industry crisis is triggering layoffs among fracking crews as well as cancelling internships among young professionals. In addition, Slav argues, the contribution of the industry to the ongoing climate crisis is a disincentive to youth. Just as laid-off oil and gas workers find work in other industries, university graduates will likewise gravitate to internships and consequent recruitment in companies "that are not victims of the whims of the most volatile commodity market in the world."

- April 7, 2020 – A survey conducted by the Louisiana Oil and Gas Association of its 450 member companies found more than 23,000 jobs in the industry to be at immediate risk due to the coronavirus pandemic and the oil glut.[2278] This would constitute 70 percent of their workforce. "To boost the oil industry, LOGA put forth several measures, which include things it has long supported: suspending severance tax collections for one year, ending government-led coastal restoration lawsuits, easing regulations at the Office of Conservation and identifying ways to expedite oil storage capacity."

- February 20, 2020 – Penn State education policy scholars found that fracking economically harms school districts and exacerbates educational inequalities.[2279] Using data from 2007-2015, they found that public school districts in Pennsylvania with

[2276] Sergio Chapa, "Texas Oil and Gas Industry Cut Record 26,300 Jobs in April," *Houston Chronicle*, May 26, 2020, sec. Energy, https://www.houstonchronicle.com/business/energy/article/Texas-oil-gas-industry-shed-record-number-of-15294860.php.
[2277] Irina Slav, "Why Young Professionals Are Steering Clear Of Oil & Gas," *OilPrice.Com*, May 11, 2020, https://oilprice.com/Energy/Energy-General/Why-Young-Professionals-Are-Steering-Clear-Of-Oil-Gas.html.
[2278] Timothy Boone, "Half of Louisiana Oil, Gas Wells Could Be Shut in, 70% of Industry Jobs Lost within 90 Days, Trade Group Survey Shows," *The Advocate*, April 7, 2020, https://www.theadvocate.com/baton_rouge/news/coronavirus/article_431c2ea0-78f9-11ea-ae04-677757648aaa.html.
[2279] Matthew Gardner Kelly and Kai A. Schafft, "A 'Resource Curse' for Education?: Deepening Education Disparities in Pennsylvania's Shale Gas Boomtowns," *Society & Natural Resources* 34, no. 1 (2021): 23–39, https://doi.org/10.1080/08941920.2020.1728000.

fracking had "lower per pupil revenues, locally-raised per pupil funding for schools, per pupil income, and per pupil property wealth," than otherwise similar districts without fracking. School districts with fracking had $1,550.50 less per pupil compared to the otherwise similar districts. They concluded that fracking "may help to maintain and entrench spatial inequality across school districts."

- December 18, 2019 – A research team quantified various aspects of equity within the populations affected by the shale gas boom in Appalachia. Their findings revealed a disproportionate burden on the poor that included higher mortality risks induced by fracking-related air pollution. Poorer residents also derived fewer economic benefits from the industry.[2280] In addition to documenting that mortality risk from natural gas pollution increased as income decreased, the team also documented inequities in employment. In states where fracking takes place, 80 percent of natural gas-related employment was concentrated in just 10 percent of counties. Though authors discussed options for incorporating equity in planning and policy related to shale gas systems, their recommendations pointed to the need for fundamental socio- technical change in energy systems, in order to reduce or relieve "disproportionate costs to the poor and to future generations." A companion study to this one is described below (November 18, 2019).

- November 18, 2019 – A Carnegie Mellon, Stanford, and Princeton University study examined both the human health and climate impacts of fracking in Appalachia and was the first to put dollar values on some of the external and cumulative costs. The team found that premature deaths caused by the industry's pollution had an economic cost of $23 billion, while climate impacts cost an additional $34 billion, from 2004-2016. Their findings showed that one year of life is lost for every three job years created by the industry. These premature deaths extend beyond the communities where the gas wells—and attendant employment benefits—are located, with almost half occurring downwind of the fracking areas in urban regions of the Northeast. While these health harms from air pollution effects follow the boom-and-bust cycles of the industry, the climate harms will persist for generations well beyond the end of fracking. The study's lead author, Erin Mayfield, a postdoctoral research associate at the Princeton Environmental Institute, said, "Private firms across the supply chain have not faced the full costs of natural gas development… and the public has effectively subsidized greenhouse gas and air pollution emissions that result in climate change and health impacts."[2281, 2282] See also the companion study above (December 8, 2019).

- October 9, 2019 – In a nationwide study, an Ohio State team examined social changes linked to fracking from 2009 to 2014. They anticipated that oil and gas employment growth during the shale boom would increase marriage rates. However, they found just

[2280] Erin N. Mayfield et al., "Quantifying the Social Equity State of an Energy System: Environmental and Labor Market Equity of the Shale Gas Boom in Appalachia," *Environmental Research Letters* 14, no. 12 (2019): 124072, https://doi.org/10.1088/1748-9326/ab59cd.
[2281] Erin N. Mayfield et al., "Cumulative Environmental and Employment Impacts of the Shale Gas Boom," *Nature Sustainability* 2, no. 12 (December 2019): 1122–31, https://doi.org/10.1038/s41893-019-0420-1.
[2282] "Is Shale Development Worth the Costs? A CMU Study Says No.," *Pittsburgh Post-Gazette*, August 2019, https://www.post-gazette.com/news/health/2019/12/08/shale-development-natural-gas-drilling-fracking-costs-health-study-pennsylvania-cmu/stories/201912060038.

the opposite. Marriage rates decreased and divorce rates increased. Specifically, fracking was linked to a decline in the share of the population who were married, an increase in the proportion of divorced people, and had little effect on those who never married or cohabited.[2283] Authors discuss the range of potential negative and positive consequences of this demographic restructuring in rural communities along with the possible role that inevitable fracking busts may play in altering marriage behaviors as compared to boom-phase fracking.

- October 1, 2019 – Fracking booms can bring gains in income, employment, and salaries, and increases in housing prices and rent. An economic analysis of nine U.S. shale regions found that, despite improvements in certain economic indicators such as these, fracking was also linked to "deterioration in local amenities, which may include increases in crime, noise, and traffic and declines in health.[2284] The researchers developed a measure called "willingness to pay" for allowing fracking, which was about $2,500 per household annually. They emphasized that they found "evidence of important heterogeneity in the local net benefits," and understanding these differences "is a first-order question for researchers and policymakers interested in assessing the impacts of allowing fracking in their community."

- August 29, 2019 – Economists found reduced student test scores and reduced student attendance in Texas school shale oil districts, compared to non-shale districts.[2285] Despite tripling of the local tax base in these districts in the study period from 2001 to 2014, schools did not spend money on teacher and other school staff wages. "As the gap between teacher wages and private sector wages grew, so did teacher turnover and the percentage of inexperienced teachers, which helps explain the decline in student achievement." Researchers noted that per capita student spending did increase in other needed areas such as renovations and debt service, but this type of spending did not prevent the declines in student achievement. They noted that oil and gas revenue has entirely bypassed the education section in other fracking states.

- August 7, 2019 – The *Houston Chronicle* reported on data from two research firms that compared differences between mid-2018 and mid-2019 in numbers of wells fracked and numbers of workers in the Permian Basin. The data showed that the wells were being fracked and completed at record numbers, but with the number of crews down almost 20 percent. The article stated, "the work is being done with far fewer people as energy

[2283] Michael Shepard, Michael Betz, and Anastasia Snyder, "The Shale Boom and Family Structure: Oil and Gas Employment Growth Relationship to Marriage, Divorce, and Cohabitation," *Rural Sociology* 85, no. 3 (2020): 623–57, https://doi.org/10.1111/ruso.12306.
[2284] Alexander W. Bartik et al., "The Local Economic and Welfare Consequences of Hydraulic Fracturing," *American Economic Journal: Applied Economics* 11, no. 4 (2019): 105–55, https://doi.org/10.1257/app.20170487.
[2285] Joseph Marchand and Jeremy G. Weber, "How Local Economic Conditions Affect School Finances, Teacher Quality, and Student Achievement: Evidence from the Texas Shale Boom," *Journal of Policy Analysis and Management* 39, no. 1 (2020): 36–63, https://doi.org/10.1002/pam.22171.

companies scale back costs to appease Wall Street investors concerned about overspending."[2286]

- July 6, 2019 – Substantial evidence shows that that vulnerable women face increased violence in boomtowns full of transient laborers building big resource projects, according to a report by the Canadian National Inquiry into Missing and Murdered Indigenous Women and Girls. Pertinent to the impending approval of the Trans Mountain pipeline, the report is based on the testimony of thousands of survivors and family members of murdered and missing women, and it links "man camps" with higher rates of violence against Indigenous women. The report also raises concern about vulnerable women entering the sex trade near activity such as pipeline projects. "Women are made vulnerable by the combination of exclusion from high-paying resource jobs and having to make ends meet in a town where the cost of living is rising," according to Indigenous advocate Connie Greyeyes.[2287]

- July 5, 2019 – A statewide survey of 2,240 Pennsylvanians found that 23.4 percent of respondents had encountered fracking-related activities, including well sites, related truck traffic, pipelines, or fracking workers, during outdoor recreation. Over 12 percent reported being substantially impacted by fracking activities in their recreation, and almost 14 percent changed their plans, avoided a certain area, or no longer traveled to the Pennsylvania for outdoor activities due to these encounters. Outdoor recreation impacts were highest in the North Central and Southwest Pennsylvania, where fracking is most prominent.[2288] As noted in coverage of the study by *Consumer Affairs,* "outdoor activities provide a huge influx of income to the U.S. government, and interfering with such activities will start to interfere with those profits."[2289]

- March 16, 2019 – University of Rochester environmental and health economists found that the public announcement of the proposed Constitution pipeline led to a led to a 9.29 percent (about $12,000) decrease in sale price for New York State homes located within three kilometers of its main route, compared to houses between 3-20 kilometers away.[2290] "Our results suggest that homebuyer expectations of the environmental externalities of natural gas pipeline construction and operations are large and negative." (The

[2286] Jordan Blum, "Permian Fracking Activity Sets New Records with Fewer People," *Houston Chronicle*, August 7, 2019, https://www.chron.com/business/energy/article/Permian-fracking-activity-breaks-new-records-with-14286709.php.
[2287] Lori Culbert, "Indigenous Women Vulnerable to 'Man Camps': MMIWG Report. So, What's at Stake with the Pipeline Approval?," *Vancouver Sun*, July 6, 2019, https://vancouversun.com/business/energy/mmiwg-report-says-indigenous-women-vulnerable-in-resource-towns-whats-at-stake-with-the-pipeline-approval.
[2288] Michael D. Ferguson et al., "The Impacts of Shale Natural Gas Energy Development on Outdoor Recreation: A Statewide Assessment of Pennsylvanians," *Journal of Outdoor Recreation and Tourism* 27 (2019): 100230, https://doi.org/10.1016/j.jort.2019.100230.
[2289] Kristen Dalli, "Shale Natural Gas Development Hampers Consumer Outdoor Activities, Study Finds," *Consumer Affairs*, August 1, 2019, https://web.archive.org/web/20210302210635/https://www.consumeraffairs.com/news/shale-natural-gas-development-hampers-consumer-outdoor-activities-study-finds-080119.html.
[2290] Andrew Boslett and Elaine Hill, "Shale Gas Transmission and Housing Prices," *Resource and Energy Economics* 57 (2019): 36–50, https://doi.org/10.1016/j.reseneeco.2019.02.001.

Constitution pipeline was canceled in February 2020 after years of public opposition and failure to obtain a state water permit.)

- March 14, 2019 – A Canadian team reviewed the research published between 2009–2018 on the impacts on communities of "the whole suite of technologies that aid in the exploration, extraction, and transportation" of natural gas. This first review of impacts across the supply chain found most of the studies addressed upstream communities (those adjacent to the gas extraction), and that midstream and downstream communities were understudied. Midstream communities were those located in transportation corridors, such as near pipelines, and downstream communities were those near processing and shipping facilities. The study identified 28 community impacts across four broad categories: environmental impacts; impacts to infrastructure and service delivery; impacts on policy, regulation, and participation in decision-making; and socioeconomic impacts. In each area, the reviewers identified common findings, mixed results across studies, and research gaps. For social service delivery, for example, the review found significant effects from the boom and bust cycles. In the boom cycle these included "increased pressure on limited infrastructure, affordable housing and daycare, recreational and child/youth programs, and social services to address alcohol and drug addictions, domestic violence, and crime." In the bust cycle there is a continued need for social services, especially as created by unemployment, economic hardship, local business closures, dropping property values, and out-migration. In this period though, there may be cuts to social services, and "peer-reviewed articles rarely focused on the capacity of local governments to address impacts before, during, and after they happen."[2291]

- December 10, 2018 – Although Pennsylvania has been able to realize modest short-term economic growth from fracking, policy researchers found that the state has also allowed costs to be externalized to public health, the environment, and community integrity. Despite emerging evidence on adverse public health effects, there remain significant uncertainties about these externalized costs, especially with regard to the long term. Research done in the state has shown "significant remaining uncertainties in detecting and attributing responsibility for groundwater contamination" associated with fracking. Intensive gas extraction in Pennsylvania can strain communities by several pathways: increased demand for emergency medical and mental health services; loss of housing for low income residents displaced by temporary, out-of-state workers; and increased traffic violations and arrests for driving under the influence. Emergencies at fracking sites can also strain or exceed the capabilities of local emergency response organizations. At the state level, policy weaknesses include failure to mandate the disclosure of fracking chemicals, failure to exercise adequate inspection and enforcement, and failure to institutionalize "stewardship of rents extracted from a nonrenewable resource for future generations."[2292]

[2291] Chris G. Buse et al., "Locating Community Impacts of Unconventional Natural Gas across the Supply Chain: A Scoping Review," *The Extractive Industries and Society* 6, no. 2 (2019): 620–29, https://doi.org/10.1016/j.exis.2019.03.002.
[2292] Brian Alexander Chalfant and Caitlin C. Corrigan, "Governing Unconventional Oil and Gas Extraction: The Case of Pennsylvania," *Review of Policy Research*, 2018, e0001, https://doi.org/10.1111/ropr.12319.

- November 21, 2018 – The presence of drilling and fracking operations is linked with fewer visits to overnight recreation sites in National Forests in western states. As part of a USDA Forest Service study that analyzed visitor use data from 27 National Forests with 722 overnight use areas, researchers found that, on average, each additional oil or gas well within a five-kilometer radius of a site was linked to six fewer visits annually. Within a five-kilometer radius, the distance between the well and the campground was not a significant factor. The researchers did not speculate on the overall user experience but wrote that their results do "suggest that the presence of oil and gas development may have a significant enough effect on the user experience to motivate users to recreate elsewhere."[2293]

- October 28, 2018 – In 15 states between 2000 and 2013, intensive shale oil and gas drilling activity was linked with 41,760 fewer students enrolled in school per year in grades 11 and 12. This phenomenon was greatest in states with a younger compulsory schooling age (16 years of age instead of 17 or 18), in states with a lower effective tax rate on oil and gas production, and in rural counties with traditional mining or persistent poverty.[2294] The results of the study, conducted by a team of economists, aligned with historical evidence from the 1970s energy boom as well as complementary research from the 2000s, both showing that oil and gas booms "can discourage educational attainment by increasing the opportunity cost for students to stay in school." (See entry below for July 2015.)

- September 24, 2018 – An *E&E* investigation examined cities in North Dakota, Pennsylvania, and Oklahoma that are experiencing lingering financial and social disruptions following oil and gas booms. In Oklahoma, "the state Legislature is trying to fix what some viewed as a string of bad fiscal decisions that led to cuts in education and other services." In Pennsylvania, communities are still roiled by "a series of bitter disputes about whether local landowners were getting their fair share of royalties from gas drilling." In North Dakota, the debt held by the city of Williston was high for a town its size, with its manageability dependent on continuing oil tax income from the state.[2295]

- August 22, 2018 – Marking a decade since Marcellus Shale fracking began in earnest, a five-university research team presented a review of impacts to people, policy, and culture in the greater mid-Atlantic region of the United States. The review's geographic and thematic sections address a range of impacts on Pennsylvania communities and a discussion of the less-studied communities in West Virginia and Ohio undergoing fracking. Economic impacts in Pennsylvania, contrary to what political and business interests typically tout, are mixed. Employment data showed that positive effects for local residents "are relatively small and temporary, in large part because much of the

[2293] Rebecca Rasch, Matt Reeves, and Colin Sorenson, "Does Oil and Gas Development Impact Recreation Visits to Public Lands? A Cross-Sectional Analysis of Overnight Recreation Site Use at 27 National Forests with Oil and Gas Development," *Journal of Outdoor Recreation and Tourism* 24 (2018): 45–51, https://doi.org/10.1016/j.jort.2018.11.001.
[2294] Na Zuo, Jack Schieffer, and Steven Buck, "The Effect of the Oil and Gas Boom on Schooling Decisions in the U.S," *Resource and Energy Economics* 55 (2019): 1–23, https://doi.org/10.1016/j.reseneeco.2018.10.002.
[2295] Mike Lee and Pamela King, "These Places Rode out the Boom and Bust. Now What?," *E&E News*, September 24, 2018, https://web.archive.org/web/20180924163148/https://www.eenews.net/stories/1060099341.

employment benefits from the activity goes to workers living outside the host communities." Further, among local residents, economic benefits were unequally distributed based on land ownership. In Pennsylvania, about half of lease and royalty dollars accrue to the top 10 percent of local landowners who owned the most acreage, while the bottom 70 percent of landowners collectively receive only 2.8 percent of all such dollars. "The vast majority of local residents were not rural landowners and thus were unable to take advantage of gas leasing for revenue." For poorer residents in fracking areas, "radically tightening housing markets, coupled with skyrocketing housing costs," presented fundamental economic hardships.[2296]

- June 6, 2018 – Uneven distribution of economic/service-related benefits and social/environmental costs characterize the Barnett and the Eagle Ford shale plays in Texas, according to an analysis of shale energy development in the southern United States that included both objective and perceived effects. Transportation-related hazards, deemed "the big one," were seen as the primary concern to community leaders and residents. Multiple sources and study types corroborated the objective transportation trends and harms. For example, a survey of county and city public officials in the 15-county Eagle Ford Shale region concluded that increasing transportation demands resulting from fracking "have not been met with needed state resources to maintain and/or upgrade transportation facilities to meet the increased volume and weight of vehicles using the transportation system in local communities." An Academy of Medicine, Engineering and Science of Texas Task Force on Environmental and Community Impacts of Shale Development in Texas likewise concluded, "the level of funding to address the impacts to the transportation infrastructure and traffic safety in the oil and gas industry area is low relative to the magnitude of the impact." This analysis also described uneven distribution of benefits. For example, individuals and energy companies located outside of the region held 96 percent of Eagle Ford mineral wealth.[2297]

- May 21, 2018 – Public administration scholars at Binghamton University interviewed 43 local government officials in 26 municipalities in high-density drilling areas of the Marcellus Shale regions of Pennsylvania.[2298] They considered these officials to be "on the frontlines" of social equity issues linked to the geographic distribution of environmental costs versus economic benefits of fracking. They found that most municipal officials "explicitly recognized that there were distributional benefits-sharing problems associated with shale gas drilling," while most also believed shale gas drilling was a net positive for their communities. Still, "there were mixed feelings regarding whether the financial gains of drilling compensated for the environmental impacts," with some expressing "incredulity" at the idea that money compensated for impact. Researchers demonstrate that local officials are aware of equity issues, with some taking

[2296] Jeffrey B. Jacquet et al., "A Decade of Marcellus Shale: Impacts to People, Policy, and Culture from 2008 to 2018 in the Greater Mid-Atlantic Region of the United States," *The Extractive Industries and Society* 5, no. 4 (2018): 596–609, https://doi.org/10.1016/j.exis.2018.06.006.
[2297] Gene L. Theodori, "Shale Energy Development in the Southern United States: A Review of Perceived and Objective Social Impacts," *The Extractive Industries and Society* 5, no. 4 (2018): 610–18, https://doi.org/10.1016/j.exis.2018.05.006.
[2298] Pamela A. Mischen and Stephanie Swim, "Social Equity and 'Fracking': Local Awareness and Responses," *Administration & Society* 52, no. 1 (2020): 138–65, https://doi.org/10.1177/0095399718774032.

action to reduce inequities, but that action in their communities often conflicts with convictions about property rights.

- March 4, 2018 – Local governments in highly rural regions experiencing large-scale growth in oil and gas activity faced the greatest fiscal challenges, according to a study evaluating the effects of this development in 21 U.S. regions during boom and bust periods. "Increased crime, vehicle accidents, and other public safety issues were major challenges," and "the scale of these challenges tended to track the scale of population growth and a region's rurality." Though revenues from property and sales taxes and other sources resulted in a net gain for many local governments, the volatility of industry activity and population growth created especially difficult challenges for some municipalities. In a rural western Colorado city, for example, residents were faced with increased taxes, as well as increased water and wastewater fees to service the debt incurred by needed upgrades.[2299]

- February 13, 2018 – Economists found that Oklahoma home prices in 2006 to 2014 declined by three to four percent after experiencing a moderate earthquake. Further, sale prices for the properties affected by the most intense earthquakes were estimated to have declined from 3.5-10.3 percent. The study also found that houses were on the market significantly longer following earthquake exposure. The intensity of a quake for each property was determined by linking earthquake magnitude to the distance of the home from its epicenter. The researchers wrote, "Oklahoma provides an exceptional case study as the state most affected by sudden changes in seismic frequency and intensity," and that although the exact proportion of earthquakes induced by oil and gas activity is not certain, "the Oklahoma Geological Survey has recognized that the majority of earthquakes are likely to be induced." They concluded that the rise in earthquake activity "has inflicted substantial costs on homeowners in Oklahoma."[2300]

- January 25, 2018 – In the Marcellus Shale region, counties experiencing a fracking boom suffered a 30 percent increase in violent crime, compared to those with no gas boom. Aggravated and sexual assaults were the crimes primarily responsible for this increase. This research took advantage of "natural experiment" conditions in the region, with a prohibition on fracking in New York State and a fracking boom across the border in Pennsylvania. The study used 2004 to 2012 county-level data from New York and Pennsylvania Marcellus Shale regions, on unconventional gas wells drilled, and on seven "FBI Index I" offenses. The offenses were violent crimes (aggravated assault, rape, robbery, and murder) and property crimes (larceny, burglary, and auto theft). While violent crimes increased in fracking boom areas, property crimes did not. The research featured many controls to isolate the effects of the fracking economy on crime rates. In addition, "victimization costs" were estimated to be $8.1 million per year in high fracking counties. "Policymakers along with oil and natural gas proponents often cite the benefits

[2299] Richard G. Newell and Daniel Raimi, "The Fiscal Impacts of Increased U.S. Oil and Gas Development on Local Governments," *Energy Policy* 117 (2018): 14–24, https://doi.org/10.1016/j.enpol.2018.02.042.
[2300] Ron Cheung, Daniel Wetherell, and Stephan Whitaker, "Induced Earthquakes and Housing Markets: Evidence from Oklahoma," *Regional Science and Urban Economics* 69 (2018): 153–66, https://doi.org/10.1016/j.regsciurbeco.2018.01.004.

in terms of jobs and income that are created in a community. However, the welfare costs of victims of crimes, among other issues, should also be considered to make optimal policy decisions."[2301]

- January 24, 2018 – The nearest full-time fire department to a deadly Quinton, Oklahoma natural gas rig explosion was nearly 30 miles away, according to an *E&E* investigation focusing on emergency response. "The deaths highlight a crucial fact of the drilling boom—much of it has occurred in rural areas where small-town police officers, sheriff's deputies and volunteer firefighters are often the first responders."[2302]

- January 13, 2018 – Sex trafficking in oil boomtowns remains a huge problem, according to interviews with 185 health and social service professionals, criminal justice personnel, industry and community representatives, and victims of violence in the Bakken oil field region. These results are reflective of the growing literature on the topic. Interviewees shared information on increases in domestic violence, dating violence, sexual assault, stalking, and sex trafficking, Findings demonstrated that sex trafficking was linked to "a confluence of underlying forces including big oil money, an increase in drug cartels and drug use, degradation of women in a male-dominated workforce, increased access to weapons, and a rise in transient populations." A noteworthy contribution of this study was the documentation that participants felt unprepared to address the needs of victims of sex trafficking, having very few resources, and limited background and experience with these problems.[2303]

- December 12, 2017 – Fracking is unlikely to be a panacea for economically marginalized rural, suburban, or urban areas, and economic optimism regarding fracking tends to be overgeneralized, according to a study analyzing national data on socioeconomic wellbeing for the years 2000 to 2011. Researchers noted that large profits for industry and economic development "may not trickle down to residents living in high-production counties," but instead often benefit a relative few, over a temporary time period. The study measured percentage of families below the poverty line in each county, average earnings, median household income, and employment status, to understand these socioeconomic impacts of oil and gas booms. Their literature review also uncovered a disparity in findings: "industry-funded studies have found substantial economic windfalls related to extraction… but the peer-reviewed literature suggests mixed or modest effects."[2304]

- September 26, 2017 – The partial abandonment of the Eagle Ford Shale dramatically hurt small business owners, according to a report by *Bloomberg.* "As the shale drillers moved

[2301] Timothy M. Komarek, "Crime and Natural Resource Booms: Evidence from Unconventional Natural Gas Production," *The Annals of Regional Science* 61, no. 1 (2018): 113–37, https://doi.org/10.1007/s00168-018-0861-x.
[2302] Mike Lee and Mike Soraghan, "Rig Wreckage Probed for Cause of Deadly Okla. Blast," *E&E News*, January 24, 2018, https://web.archive.org/web/20180124201230/https://www.eenews.net/stories/1060071777.
[2303] Thomasine Heitkamp, "Sex Trafficking in the Bakken Oil Fields" (Society for Social Work and Research, Washington, DC, 2018), https://sswr.confex.com/sswr/2018/webprogram/Paper32717.html.
[2304] Adam Mayer, Shawn K. Olson-Hazboun, and Stephanie Malin, "Fracking Fortunes: Economic Well-Being and Oil and Gas Development along the Urban-Rural Continuum: Fracking Fortunes," *Rural Sociology* 83, no. 3 (2018): 532–67, https://doi.org/10.1111/ruso.12198.

on to richer fields, the South Texas landscape became pockmarked with abandoned structures. This nimbleness—the ability to just pack up and leave at a moment's notice—may give U.S. oil companies a competitive advantage against their more rigid state-run OPEC rivals, but there is a human cost to it all." Concerning one tool and supply company in the region, the investigation found: "During the height of the Eagle Ford boom, R. Katz was supplying as many as 52 rigs and employing as many as 18 people in its office outside Cuero's main strip. Today, it's got 11 rig clients and three employees."[2305]

- August 10, 2017 – Researchers from the independent, nonpartisan economic research group Resources for the Future studied the impacts of unconventional oil and gas booms on public school districts in the oil- and gas-producing states Pennsylvania, Ohio, West Virginia, North Dakota, Montana, and Colorado between 2000 and 2013. Using quantitative data analysis as well as extensive interviewing with parents and students in the districts, the study addressed the effects of recent oil and gas booms on student enrollment, teachers, public education finances, and student achievement metrics. Though divergent trends were found between school districts in the eastern versus western U.S., "nearly all boom districts reported heightened stress from financial volatility." Though some districts had a statistically positive increase in per student funding while others had a decline, "the study found that greater revenues do not always translate into increased educational outcomes…. One western Colorado school district had to operate on a four-day-a week schedule and cut academic programs because of increased economic volatility."[2306] As reported in *U.S. News and World Report*, "the boom-and-bust cycle of the industry was found to create overwhelming stress on local districts as students and teachers were moving in and out of a region to meet the economic demands of drilling."[2307]

- June 18, 2017 – A Shale Task Force of the Academy of Medicine, Engineering and Science of Texas (TAMEST) developed the report, *Environmental and Community Impacts of Shale Development in Texas*, a "first-of-its-kind, comprehensive review of scientific research and related findings regarding impacts of shale oil and gas production in Texas." Transportation impacts included road damage costing Texas an estimated $1.5 to $2 billion a year, and rural crashes involving commercial vehicles increasing over 75 percent in some drilling regions. The number of fatal collisions in the Permian Basin doubled from 94 during 2006 to 2009, to 183 from 2010 to 2013. The report also noted that Texas is the only major oil and gas producing state without a "surface damage act" to protect landowners, who do not own the mineral rights on their land and have little control over oil and gas operations. The report, which also addressed topics such as

[2305] Dan Murtaugh, "Life in the Oil Ghost Towns of Texas," *Bloomberg*, September 26, 2017, https://www.bloomberg.com/news/features/2017-09-26/the-oil-ghost-towns-of-texas.
[2306] Nathan Ratledge and Laura Zachary, "Impacts of Unconventional Oil and Gas Booms on Public Education: A Mixed-Methods Analysis of Six Producing States" (Resources for the Future, 2017), https://www.rff.org/publications/reports/impacts-of-unconventional-oil-and-gas-booms-on-public-education-a-mixed-methods-analysis-of-six-producing-states/.
[2307] Eric Englert, "Fracking Brings Challenges to Local School Systems," *US News & World Report*, August 10, 2017, //www.usnews.com/news/national-news/articles/2017-08-10/fracking-brings-challenges-to-local-school-systems.

seismicity, air, and water, noted that the various impacts of oil and gas development "can't be studied or addressed in isolation." Authors continued, "[t]hese connections are important and pervasive, but are not well-studied yet." TAMEST includes all of the state's Nobel Laureates, plus Texas-based members of the National Academies of Sciences, Engineering, and Medicine.[2308]

- April 6, 2017 – The economic impacts of fracking at the advent of the Marcellus Shale boom is an understudied topic. The onset of fracking was so rapid that academics were challenged to provide accurate and timely information to policymakers, and the one major paper that did appear in 2011 did not clearly disclose its industry sponsorship. A Pennsylvania Department of Community & Economic Development-funded study set out to investigate those early years. In addition to scrutinizing available data, the authors conducted a survey of 1,000 landowners in Bradford and Tioga counties, the two counties with the most fracked wells in Pennsylvania at the start of the boom. From the 501 returned surveys, they determined residents saved more than half of their earliest royalty and lease income, which "may or may not ultimately be spent within Pennsylvania." Hence, the windfalls from mineral rights created "little economic impact during the year received." Further, the study's overall "lower-bound" estimate of economic impacts for 2009 found that fully 15.4 percent of these mineral rights were owned by non-residents. At the same time, survey results showed that 37 percent of the workforce consisted of non-residents with only half of their income staying in the state. This study's upper-bound jobs count for 2009 was substantially lower than the estimates that made at the time. In addition, the study urged caution regarding future jobs predictions, as the sharp decline between 2011 and 2013 "was totally unexpected" and was not captured in a 2010 forecast for jobs in 2020.[2309]

- April 5, 2017 – Economists at Colorado State University quantified the "substantial environmental costs associated with hydraulic fracturing," as part of an analysis of the market and non-market costs and benefits of fracking in 14 U.S. states. These costs were "dominated by $27.2 billion ($12.5–$41.95 billion) health damages from air pollution." They also found costs including "$3.8 billion ($1.15–$5.89 billion) in greenhouse gas emissions, $4 billion ($3.5–$4.45 billion) in wildlife habitat fragmentation, and $1 billion ($0.5–$1.6 billion) in pollution of private drinking water wells." Results also showed a disconnect between those reaping economic rewards from fracking and those paying the price: the "benefits" (mostly in the form of lower natural gas prices to residential, commercial, and industrial consumers) were geographically dispersed while the costs tended to concentrate in localized areas where drilling took place. Although the most comprehensive economic study to date, this analysis was not able to fully quantify all costs, including those related to water contamination (beyond surface-spill related costs for damage to private wells); diminishment of open spaces and aesthetics for community members; and seismic activity. The authors concluded that costs might well outweigh the

[2308] The Academy of Medicine, Engineering and Science of Texas, *Environmental and Community Impacts of Shale Development in Texas* (TAMEST, 2017), https://doi.org/10.25238/TAMESTstf.6.2017.
[2309] Kyle A. Hoy, Timothy W. Kelsey, and Martin Shields, "An Economic Impact Report of Shale Gas Extraction in Pennsylvania with Stricter Assumptions," *Ecological Economics* 138 (2017): 178–85, https://doi.org/10.1016/j.ecolecon.2017.03.037.

benefits for suburban dwellers near fracking operations, as exemplified by Denton, Texas, where "nearly all the royalty money was flowing to mineral owners living elsewhere…rather than to adjacent homeowners."[2310]

- February 19, 2017 – The *New York Times* reported on the oil and gas industry's embrace of automation and its threat to preserving and bringing back jobs. Executives interviewed as part of the investigation were straightforward in their intentions to shrink their work forces. "'We want to transform our work force to the point where we need to hire fewer people,' said Joey Hall, Pioneer's executive vice president for Permian Operations." In 2016 Pioneer Natural Resources added 240 wells in West Texas without adding any new employees. A vice president at a Pennsylvania manufacturer of drilling rigs stated, "If it's a repetitive task, it can be automated, and I don't need someone to do that. I can get a computer to do that."[2311]

- February 1, 2017 – Stanford University earth science professor Robert Jackson and two professors of law assessed how a new type of "conservation easement," an established kind of legal agreement, could enable landowners to restrict fracking on their properties. A mineral estate conservation easement (MECE) can serve as a private landowner response to the demonstrable threats of fracking to property and community: "Accompanying the rise of high-volume hydraulic fracturing has been a suite of environmental and social concerns, including potential water and air contamination, greenhouse gas emissions, health effects, and community disruptions." "We support the exploration of MECEs as an additional tool for landowners to exercise their rights and responsibilities," the team concluded.[2312]

- January 26, 2017 – Automation is reducing the size of drilling crews and will lessen the number of jobs added nationally with any upturn in oil and gas operations, according to a piece on OilPrice.com. The author described predictions, including:

> Automated drilling rigs may be able in the future to reduce the number of persons in a drilling crew by almost 40 percent, from 25 workers to 15 workers, *Houston Chronicle*'s Jordan Blum writes, quoting industry analysts.

[2310] John Loomis and Michelle Haefele, "Quantifying Market and Non-Market Benefits and Costs of Hydraulic Fracturing in the United States: A Summary of the Literature," *Ecological Economics* 138 (2017): 160–67, https://doi.org/10.1016/j.ecolecon.2017.03.036.
[2311] Clifford Krauss, "Texas Oil Fields Rebound From Price Lull, but Jobs Are Left Behind," *The New York Times*, February 19, 2017, sec. Business, https://www.nytimes.com/2017/02/19/business/energy-environment/oil-jobs-technology.html.
[2312] Robert B. Jackson, Jessica Owley, and James Salzman, "Mineral Estate Conservation Easements: A New Policy Instrument to Address Hydraulic Fracturing and Resource Extraction," *The Environmental Law Reporter*, January 31, 2017, https://elr.info/news-analysis/47/10112/mineral-estate-conservation-easements-new-policy-instrument-address-hydraulic-fracturing-and-resource-ext.

> Drilling company Nabors Industries expects that it may be able to reduce the size of the crew at each well site to around 5 people from 20 workers now if more automated drilling rigs are used, Bloomberg's David Wethe says.[2313]

- December 22, 2016 – Researchers with the Energy Policy Institute at the University of Chicago measured the costs and benefits of fracking in local communities across nine U.S. shale basins. They found that, despite contributions to local economies with the arrival of fracking, residents experienced decreases in local quality of life. Spikes in crime were the most directly measurable of these effects. "Despite local governments' efforts to improve public safety—allocating 20 percent more funding—the crime rates still marginally increased." The study also found unequal distribution of benefits. Students, the elderly, and those who don't own mineral rights did not benefit at all. Their analysis found an average gain of about $1,300 to $1,900 per household per year, but these gains were offset by a reduction in the typical household's quality of life, which the authors computed at about $1,000 to $1,600 per year.[2314]

- December 21, 2016 – Economists from the University of Anchorage and Montana State University studied the impact of regional shale energy booms on crime rates across U.S. counties from 2000 to 2013, documenting increased rates of many types of crime, including assault, rape, larceny, and auto theft. In 2013, they pegged the average monetary cost of these additional crimes at $2 million per county. Researchers emphasized these results represented short-term costs only, as they could not predict how crimes rates and attendant costs will accrue over longer periods of time, as, for example, if criminal behavior and labor migration facilitate a slow drain of human and physical capital from the region and propagate "a long-term resource curse." The study also found "that registered sex offenders moved in disproportionate numbers to boom towns in North Dakota," and "that income inequality increased as the shale boom progressed."[2315]

- May 24, 2016 – In 327 U.S. counties previously at the center of the fracking boom, overdue car loans approached their highest level in five years, and late mortgage payments also rose, according to a report by the *Financial Times* that examined data from the Federal Reserve Bank of New York. These trends stood in stark contrast to lowered overdue debt rates in the rest of the U.S. This surge in late car payments in intensely fracked areas of the United States has "exposed the damage done by the collapse in drilling activity and marred broadly positive trends for late debt payments by American consumers."[2316]

- May 8, 2016 – With the downturn in the fracking industry, Wisconsin's sand mining sector, which provides silica sand for fracking operations, has also slumped and prompted

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[2313] Tsvetana Paraskova, "Robots Over Roughnecks: Next Drilling Boom Might Not Add Many Jobs," *OilPrice.Com*, January 26, 2017, https://oilprice.com/Energy/Energy-General/Robots-Over-Roughnecks-Next-Drilling-Boom-Might-Not-Add-Many-Jobs.html.
[2314] Bartik et al., "The Local Economic and Welfare Consequences of Hydraulic Fracturing."
[2315] Alexander James and Brock Smith, "There Will Be Blood: Crime Rates in Shale-Rich U.S. Counties," *Journal of Environmental Economics and Management* 84 (2017): 125–52, https://doi.org/10.1016/j.jeem.2016.12.004.
[2316] Sam Fleming, "US Fracking Bust Sparks Surge in Car Debt," *Financial Times*, May 24, 2016, https://www.ft.com/content/a4cb1270-21c2-11e6-aa98-db1e01fabc0c.

significant layoffs and job losses in both 2015 and 2016, according to a report by Eau Claire's *Leader-Telegram*. "This is what the bust part of the boom-and-bust cycle of the energy sector looks like, and it's something west-central Wisconsin residents, who are mostly new to the industry, aren't used to seeing." Other companies that supply goods and services to sand mining operations in the region have also experienced a downturn.[2317]

- March 8, 2016 – A DeWitt County, Texas judge estimated it will cost his county $432 million to rebuild its roads, noting that if a road "leads to a rig site, it's bound to be a broken road." The judge stated that ultimately the companies would pay a large share.[2318]

- February 22, 2016 – *Inside Energy* investigated oil-industry related wage theft claims in the West, finding "a growing number of oil workers are turning to the courts, saying they weren't paid fairly even when times were good." Between 2010 and 2015, wage theft suits against oil and gas companies in Colorado increased by a factor of nine, and in Texas nearly ten times. The investigation found that oil and gas companies were consistently among the top violators of wage laws—especially in failure to pay overtime. A federal investigation of the industry led to the recovery of $40 million dollars in unpaid wages. One of the officers involved in the investigations is quoted saying, "We have found cases where workers were not even paid the minimum wage, because they're working so many hours…. So the idea that they're being highly compensated, in some cases, they're not."[2319]

- January 13, 2016 – A fire on a fracking site in Grady County, Oklahoma that consumed 22 oil tankers required the response of six regional fire departments.[2320]

- December 15, 2015 – The value of homes that rely on well water in Pennsylvania dropped an average of $30,167 when fracking took place within 1.5 kilometers, according to a study by Duke University researchers published in the *American Economic Review*. For these groundwater-dependent homes, a fracking well located within one kilometer was linked to a 13.9 percent average decrease in values; homes with wells at least two kilometers away maintained their value. The study was based on home sales between 1995 and 2012 in 36 counties. Researchers stated that their figures may not fully reflect the total costs associated with groundwater contamination risk, as, for example, when homeowners purchase expensive home water filtration systems. Though their study does not incorporate data on actual contamination, concerns about contamination can

[2317] Eric Lindquist, "Silent Sandbox: Once Booming Frac Sand Industry Continues Major Downturn," *Leader-Telegram*, May 8, 2016, https://www.leadertelegram.com/news/front-page/silent-sandbox-once-booming-frac-sand-industry-continues-major-downturn/article_b6c1877b-3586-588f-a2b6-5cb2fe9b49ce.html.
[2318] Concetta Callahan, "Fracking Fall-off Leaves South Texas Roads a Mess," *KSAT*, March 8, 2016, sec. News, https://www.ksat.com/news/2016/03/08/fracking-fall-off-leaves-south-texas-roads-a-mess/.
[2319] Dan Boyce, "Wage Theft Claims Surge As Oil Prices Fall," *Inside Energy*, February 22, 2016, http://insideenergy.org/2016/02/22/wage-theft-claims-surge-as-oil-prices-fall/.
[2320] K. Querry and Lorne Fultonberg, "Firefighters Extinguish Damaging Grady Co. Fracking Fire," *KFOR.Com Oklahoma City*, January 13, 2016, https://kfor.com/news/all-lanes-of-traffic-shut-down-due-to-large-oil-rig-fire/.

significantly affect property values. Researchers found "strong evidence of localized costs borne particularly by groundwater-dependent homes."[2321]

- December 8, 2015 – Even as housing prices in shale gas-areas of Pennsylvania have dropped along with fracking activity, many seniors and people living on low incomes are still being priced out of the market, *StateImpact* reported. Pennsylvania still lacks a quarter million affordable rental homes for people in poverty despite a 2012 law requiring gas companies to pay well fees intended to offset the costs of affordable housing programs in communities where drilling is occurring.[2322]

- December 2, 2015 – "The local economy is feeling the pinch" of the downturn of activity in Pennsylvania's gas fields, according to a Reuters report. The late 2015 slump marked a turning point in Marcellus Shale fracking. Regional economic effects reported include empty hotel rooms and foreclosure notices in Lycoming County at their highest since data were first collected.[2323]

- October 7, 2015 – Vehicular collisions and Texas fracking activity are closely linked, according to a report by the Texas A&M University Transportation Institute. Researchers analyzed the number of crashes and injuries across Texas during the period from 2006 to 2009, when drilling and fracking operations were intensive over the Barnett Shale, as well as from 2010 to 2013, when activity increased in the Permian Basin in West Texas and the Eagle Ford Shale in South Texas, and decreased in the Barnett. Collisions increased where shale gas activity increased and decreased where it slowed down.[2324] Quoted in the *Texas Tribune*, report co-author Cesar Quiroga said, "The two trends correlated so well, and they were perfectly aligned ….We could use this as a predictive model."[2325] Further, the increase was greater in South Texas, the region that relies most heavily on horizontal, hydraulic fracking requiring millions of gallons of water and sand to be trucked in, compared to West Texas which does use fracking but also more simple, vertical wells. The comprehensive cost of these collisions was estimated to be about $2 billion more from 2010 to 2013—in both the Eagle Ford and Permian Basin—compared to the previous period.

- September 30, 2015 – The North Dakota Bureau of Criminal Investigation was set to hire nine new agents, reported the *Billings Gazette*, "…allowing for more attention to cases of

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[2321] Lucija Muehlenbachs, Elisheba Spiller, and Christopher Timmins, "The Housing Market Impacts of Shale Gas Development," *American Economic Review* 105, no. 12 (2015): 3633–59, https://doi.org/10.1257/aer.20140079.
[2322] Marie Cusick, "Despite Drilling Slowdown, Rents Still High in Fracking Boomtowns," *State Impact Pennsylvania*, December 8, 2015, https://stateimpact.npr.org/pennsylvania/2015/12/08/despite-drilling-slowdown-rents-still-high-in-fracking-boomtowns/.
[2323] Edward McAllister, "America's Biggest Gas Field Finally Succumbs to Downturn," *Reuters*, December 2, 2015, https://www.reuters.com/article/us-usa-marcellus-decline-insight-idUSKBN0TL0CY20151202#W0DRBI8eM4MKscSV.97.
[2324] Cesar Quiroga and Ioannis Tsapakis, "Oil and Gas Energy Developments and Changes in Crash Trends in Texas," Final Report (Transportation Policy Research Center, October 2015), http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/PRC-15-35-F.pdf.
[2325] Jim Malewitz, "Report: Traffic Crashes Related to Energy Boom Cost Billions," *The Texas Tribune*, October 7, 2015, https://www.texastribune.org/2015/10/07/report-shows-huge-toll-energy-boom-traffic-crashes/.

human trafficking and organized crime in western North Dakota … as increased oil production resulted in growing populations."[2326]

- September 29, 2015 – "New residential units sit empty as gas production falls," *HousingWire Magazine* wrote, following up on their earlier reporting describing the link between the drilling boom and the real estate boom in the Bakken shale region of North Dakota. Economic data indicate that Bakken drilling is not lasting long enough to sustain the building explosion.[2327]

- September 9, 2015 – Most local governments in Western North Dakota and Eastern Montana's Bakken region have experienced net negative fiscal effects, according to a Duke University analysis published by the National Bureau of Economic Research. These trends were also seen in municipalities in rural Colorado and Wyoming, which also struggled to manage fiscal impacts during recent oil and gas booms, but in these two states the fiscal impact eased as drilling activity slowed.[2328] Referencing the report, *McClatchy DC* wrote, "North Dakota cities and counties have been slammed." Municipal challenges have included providing water and sewer infrastructure, substantial damage to roads, soaring housing prices, and strained emergency services.[2329]

- August 27, 2015 – Fracking in or near public parks could cause tourists to stay away and lead to a decline in park use, according to a report published by a team of tourism, recreation, and sport management researchers from the University of Florida, North Carolina State University, and Florida State University. Using data collected from 225 self-identified park users from Pennsylvania, Ohio, West Virginia, Kentucky, and Tennessee, researchers reported that only one-third of participants were willing to participate in recreational activities near fracking operations, compared to 38 percent unwilling, and 29 percent neutral. Forty-six percent of respondents supported a ban on fracking on public lands, while 20 percent agreed with promoting fracking on public lands.[2330]

- July 1, 2015 – Britain's Department for Environment, Food & Rural Affairs released previously redacted sections of a report on the impacts of drilling and fracking. The report found that housing prices near fracking wells would likely fall up to seven percent for houses within a mile of wells. Furthermore, properties within one to five miles of

[2326] Nick Smith, "North Dakota to Hire 9 More Criminal Investigation Agents," *Billings Gazette*, September 30, 2015, https://billingsgazette.com/news/state-and-regional/montana/north-dakota-to-hire-9-more-criminal-investigation-agents/article_a4192344-c9b0-51cc-9693-5a4335f5be05.html.
[2327] Ben Lane, "Is Fracking about to Bust Housing in North Dakota?," *HousingWire*, September 29, 2015, sec. Mortgage, Real Estate, https://www.housingwire.com/articles/35196-is-fracking-about-to-bust-housing-in-north-dakota/.
[2328] Richard Newell and Daniel Raimi, "Shale Public Finance: Local Government Revenues and Costs Associated with Oil and Gas Development" (Cambridge, MA: National Bureau of Economic Research, September 2015), https://doi.org/10.3386/w21542.
[2329] Sean Cockerham, "Oil Boom a Loser for North Dakota Cities, Counties, Study Finds," *McClatchy Washington Bureau*, September 9, 2015, https://www.mcclatchydc.com/news/nation-world/national/economy/article34552824.html.
[2330] Tim Kellison et al., "Fracking & Parkland – Research Report," Research Report, 2015, http://plaza.ufl.edu/tkellison/_/Fracking.html.

fracking sites could incur additional insurance costs. The report warned of environmental damages, including from leakage of fracking waste fluids, and found that public health could be affected indirectly through consumption of contaminated wildlife, livestock, or agricultural products. The report also found potential for some benefits, such as job growth.[2331]

- July 2015 – A working paper by researchers with the National Bureau of Economic Research found that fracking resulted in an increase in male teen high school dropout rates. "Our estimates imply that, absent fracking, the male-female gap in high school dropout rates among 17- 18-year olds would have narrowed by about 11 percent between 2000 and 2013 instead of remaining unchanged." The authors explained that by increasing the demand for low-skilled labor, fracking could slow growth in educational attainment. They noted that the relative wage boost from fracking may be only temporary. Indeed, by the end of the sample period, the benefits had started to wane as the labor demand from fracking appeared to no longer favor dropouts. Thus, the fracking boom may be inhibiting educational achievement among young men who "would already be near the bottom of the skill distribution, with possible implications for future productivity and the social safety net."[2332, 2333]

- March 20, 2015 – The U.S. Attorney for Western New York linked a rise in production of methamphetamine to use among workers in the fracking fields of northern and western Pennsylvania. Surging demand for the drug, which allows users to stay awake for 48 to 72 hours, may be related to the extremely long working hours that employees in the gas industry must endure.[2334]

- January 4, 2015 – A documentary by Forum News Service, "Trafficked Report," revealed that sex trafficking, including of children, in the Bakken oil fields of North Dakota was a significant problem.[2335] The dynamics of the oil boom, with an influx of out-of-state and primarily male workers far from their families, created an increase in demand for prostitution.[2336]

[2331] Adam Vaughan and Rowena Mason, "Fracking Could Hurt House Prices, Health and Environment, Official Report Says," *The Guardian*, July 1, 2015, sec. Environment, https://www.theguardian.com/environment/2015/jul/01/fracking-could-hurt-house-prices-health-and-environment-official-report-says.
[2332] Elizabeth U. Cascio and Ayushi Narayan, "Who Needs a Fracking Education? The Educational Response to Low-Skill Biased Technological Change," Working Paper, Working Paper Series (National Bureau of Economic Research, July 2015), https://doi.org/10.3386/w21359.
[2333] Sho Chandra, "Fracking Jobs Encouraged American Teens to Become High School Dropouts," *Bloomberg*, July 14, 2015, https://www.bloomberg.com/news/articles/2015-07-14/fracking-jobs-encouraged-american-teens-to-become-high-school-dropouts.
[2334] Rich Newberg, "Meth Use Tied to Fracking Workers in Pennsylvania," *News 4 Buffalo*, March 20, 2015, https://www.wivb.com/news/crime/meth-use-tied-to-fracking-workers-in-pennsylvania/.
[2335] Amy Dalrymple and Katherine Lymn, "Trafficked: Sex for Sale in the Bakken," *Human Trafficking Search*, January 4, 2015, https://humantraffickingsearch.org/resource/trafficked-sex-sale-bakken/.
[2336] Jason Gaines, "The Oil Boom in North Dakota Now Has a Serious Sex-Trafficking Problem," *Business Insider*, March 9, 2015, https://www.businessinsider.com/north-dakota-sex-trafficking-prostitution-oil-boom-police-raid-2015-3.

- December 28, 2014 – The *New York Times* profiled the impacts of oil drilling and fracking on the Fort Berthold Indian Reservation in North Dakota, finding corruption, crime, and negative environmental impacts. Aside from a significant rise in jobs, which often go to transient workers, many residents "see deterioration rather than improvement in their standard of living. They endure intense truck traffic, degraded roads, increased crime, strained services and the pollution from spills, flares and illegal dumping." According to the *Times*' calculation, the reservation had seen 850 oil-related environmental incidents from 2007 through mid-October 2014, which generally went unpunished.[2337]

- December 26, 2014 – Examining Pennsylvania Department of Transportation data, Ohio's *Star Beacon* newspaper found that fracking poses a safety threat on rural roads. The paper found that Pennsylvania's five busiest drilling counties recorded 123 more heavy truck crashes in 2011 than before the gas boom began—a 107 percent increase. The paper noted the burden drilling and fracking placed on local communities and governments, including the strain on local emergency responders.[2338]

- December 17, 2014 – Heavy drilling and fracking (defined as 400 or more wells drilled within a county over 5-8 years) was positively correlated with increased crime, sexually transmitted diseases, and traffic fatalities, according to a report by the Multi-State Shale Research Collaborative.[2339] The report looked at the impacts in Pennsylvania, Ohio, and West Virginia, primarily finding statistically significant impacts in six heavily drilled counties in Pennsylvania. In those six counties, violent crime increased 17.7 percent—corresponding to about 130 more violent crimes in those counties in 2012—compared to a decrease in violent crime rates in both urban and rural non-drilling communities. Property crime increased 10.8 percent in those six counties, drug abuse rates rose 48 percent, and drunk-driving offenses rose 65 percent compared to 42 percent in rural areas with no drilling. The report found a statistically significant increase of 24 percent to 27 percent in rates of sexually transmitted diseases across drilling counties in all three states. Motor vehicle fatalities increased 27.8 percent in Pennsylvania's six high-drilling counties. The report found a modest increase in jobs, but noted that an influx of out-of-state workers at least partially explained the increases in traffic and crime.[2340]

- December 15, 2014 – A report written in French by Quebec's Advisory Office of Environmental Hearings concluded that the environmental costs of fracking in the St. Lawrence Lowlands would outweigh the potential economic benefits. In a press release, the Advisory Office of Environmental Hearings concluded that fracking "would not be

[2337] Deborah Sontag and Brent McDonald, "In North Dakota, a Tale of Oil, Corruption and Death," *The New York Times*, December 29, 2014, sec. U.S., https://www.nytimes.com/2014/12/29/us/in-north-dakota-where-oil-corruption-and-bodies-surface.html.
[2338] John Finnerty, "Fracking's Biggest Safety Threat Is on Rural Roads," *Star Beacon*, December 26, 2014, https://www.starbeacon.com/news/fracking-s-biggest-safety-threat-is-on-rural-roads/article_bc48687a-8caf-11e4-b4d9-6382c924a6f9.html.
[2339] Mark Price et al., "The Shale Tipping Point - Multi-State Shale Research Collaborative" (Multi-State Shale Research Collaborative, December 2014), http://www.multistateshale.org/shale-tipping-point.
[2340] Wallace McKelvey, "Fracking Brought Spikes in Crime, Road Deaths and STDs to Pa.: Report," *Pennlive*, December 18, 2014, https://www.pennlive.com/midstate/2014/12/fracking_brought_spikes_in_vio.html.

advantageous for Quebec because of the magnitude of the potential costs and externalities, compared to royalties that would be collected by Quebec. Other concerns also remain, including plans of social acceptability, legislation, and a lack of knowledge, particularly with respect to water resources."[2341]

- October 30, 2014 – The *New York Times* profiled the profound impact heavy drilling has had on Glasscock County, Texas, including its farming community. Farmers described increases in trash, traffic accidents, clashes around farmers selling groundwater to drillers, and economic detriment. In many cases, acres of farmland around a drill site "will probably never be suitable for fertile farming again," and farmers are "at the mercy" of what drillers want to pay for damages. The county itself receives revenue, but most of that additional money "is being used to repair roads damaged by oil field truck activity. Overall, the gains from drilling are not viewed as worth the drawbacks in a county long dominated by cotton farming."[2342]

- September 28, 2014 – A *Washington Post* investigation reported on heroin and methamphetamine addiction—and associated violent crime—among Native American communities located within the Bakken Shale oil fields. According to a chief judge for the Mandan, Hidatsa, and Arikara Nation, "The drug problem that the oil boom has brought is destroying our reservation."[2343]

- September 11, 2014 – An editor for the *Washington Post* examined jobs and manufacturing data in Youngstown, Ohio, to demonstrate that drilling and fracking are not resulting in a revitalization of the Rust Belt as some proponents and a prominent *New York Times* story asserted. The *Post* determined that in Youngstown, Ohio, the manufacturing sector has lost jobs by the tens of thousands in the last twenty years and the oil and gas industry has created approximately two thousand jobs since the recession ended. Six years prior, there were 13,000 more jobs in the Youngstown metro area than there were in summer 2014.[2344]

- September 9, 2014 – A study by researchers at Colorado State University examined the political economy of harm and crime associated with the oil and gas industry in rural Colorado, particularly around the rise of fracking. The researchers looked at complaints that citizens filed with the state, and also conducted interviews and examined other data. They found 2,444 complaints between November 2001 and June 2013 covering a range of issues including water, environment, noise, air quality, land use, and more. They

[2341] Sean McCarthy, "Fracking Dealt Another Setback by Quebec Report," *The Globe and Mail*, December 15, 2014, https://www.theglobeandmail.com/report-on-business/industry-news/energy-and-resources/bape-says-shale-gas-production-not-advantageous-for-quebec/article22096203/.
[2342] Aman Batheja, "A County Resents Oil Drilling, Despite the Money It Brings In," *The New York Times*, October 30, 2014, sec. U.S., https://www.nytimes.com/2014/10/31/us/a-county-resents-oil-drilling-despite-the-money-it-brings-in.html.
[2343] Sarah Horwitz, "Dark Side of the Boom," *The Washington Post*, September 28, 2014, http://www.washingtonpost.com/sf/national/2014/09/28/dark-side-of-the-boom/.
[2344] Jim Tankersley, "Fracking Hasn't Restored the Rust Belt's Lost Jobs," *The Washington Post*, September 11, 2014, https://www.washingtonpost.com/news/storyline/wp/2014/09/11/fracking-hasnt-restored-the-rust-belts-lost-jobs/.

characterized citizen complaints as "extensive and complex" and concluded that, regardless of the nature of the harm, most were "persistent and omnipresent" rather than short-lived, isolated problems.[2345]

- September 6, 2014 – In Williams County, North Dakota, in the Bakken Shale, increases in crime have corresponded with the flow of oil. The infusion of cash has attracted career criminals who deal in drugs, violence, and human sex trafficking. The *Williston Herald* portrayed, in a "reader's discretion advised" article, the rapid rise of "index crimes"—"violent crimes that result in the immediate loss of an individual's property, health or safety, such as murder, larceny and rape." With fewer than 100 law enforcement personnel, crime in Williams County "has risen in kind with the county's population, but funding, staffing and support training for law enforcement has not."[2346]

- September 2014 – Reporting on the social, environmental, health and safety, and economic burdens endured by localities from fracking, the magazine *Governing: The States and Localities* found that "fracking, in many cases, negatively impacts property values, which in turn depresses property tax revenue. For property owners who own the rights to the oil and gas on their land, the effects of drilling can be offset by royalty payments. But localities have no revenue offset if properties lose value."[2347]

- August 26, 2014 – The U.S. Justice Department Office on Violence Against Women awarded three million dollars to five rural and tribal communities to prosecute crimes of violence against women and provide services to victims of sexual assault, domestic violence, and stalking in the Bakken Region of North Dakota and Montana.[2348] Rationale documented by tribal leaders, law enforcement, and the FBI included, "rapid development of trailer parks and modular housing developments often referred to as 'man camps;' abrupt increase in cost of living, especially housing; rapid influx of people, including transients, in a previously rural and stable community; constant fear and perception of danger; and a lost way of life. Local and tribal officials and service providers reported that these changes have been accompanied by a rise in crime, including domestic and sexual violence."[2349]

- May 27, 2014 – A *Bloomberg News* analysis of 61 shale-drilling companies found that the economic picture of shale oil and gas is unstable. Shale debt has almost doubled over

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[2345] Tara Opsal and Tara O'Connor Shelley, "Energy Crime, Harm, and Problematic State Response in Colorado: A Case of the Fox Guarding the Hen House?," *Critical Criminology* 22, no. 4 (2014): 561–77, https://doi.org/10.1007/s10612-014-9255-2.
[2346] Tyler Bell Williston, "Modernized Slavery," *Williston Herald*, September 6, 2014, https://www.willistonherald.com/news/modernized-slavery/article_84e257d8-3615-11e4-a4f8-001a4bcf887a.html.
[2347] Frank Shafroth, "Fracking's Financial Losers: Local Governments," *Governing: The States and Localities*, August 25, 2014, sec. Archive, https://www.governing.com/archive/gov-frackings-financial-losers.html.
[2348] U.S. Department of Justice, "Associate Attorney General West Announces $3 Million in Grants to Address Violence Against Women in Rural and Tribal Communities in the Bakken Region," Press Release (U.S. Department of Justice, August 28, 2014), https://www.justice.gov/opa/pr/associate-attorney-general-west-announces-3-million-grants-address-violence-against-women.
[2349] U.S. Department of Justice, "OVW Fiscal Year 2014 Violence Against Women Bakken Region Initiative: Enhanced Response to Victims Application Guidelines," 2014.

the last four years while revenue has gained just 5.6 percent. For the 61 companies in their analysis, *Bloomberg News* reported: "In a measure of the shale industry's financial burden, debt hit $163.6 billion in the first quarter." Further, *Bloomberg* noted that drillers are caught in a bind because they must keep borrowing to pay for exploration needed to "offset steep production declines typical of shale wells…. For companies that can't afford to keep drilling, less oil coming out means less money coming in, accelerating the financial tailspin."[2350]

- May 5, 2014 – An Associated Press analysis found that traffic fatalities have spiked in heavily drilled areas of six states, whereas most other roads in the nation have become safer even as population has grown. In North Dakota drilling counties, for instance, traffic fatalities have increased 350 percent.[2351]

- April 16, 2014 – A comprehensive article in the *Albany Law Review* concluded that the risks inherent with fracking are not covered by homeowner's insurance, not fully insured by the oil and gas industry, and threaten mortgages and property value.[2352]

- April 2014 – A report by the Multi-State Shale Research Collaborative, "Assessing the Impacts of Shale Drilling: Four Community Case Studies," documented economic, community, government, and human services impact of fracking on four rural communities. The study found that fracking led to a rapid influx of out-of-state workers and, although some new jobs were created, these were accompanied by additional costs for police, emergency services, road damage, and social services. In addition, increased rents, and a shortage of affordable housing accompanied the fracking boom. Unemployment rose after one county's boom ended; in another county, unemployment stayed above the state average throughout.[2353]

- March 27, 2014 – A report by researchers at Rand Corporation determined that each shale gas well in Pennsylvania causes between $5,400 and $10,000 in damage to state roads. The report did not calculate damage to local roads, which is also significant. Researchers used estimates of truck trips that are significantly below the number

[2350] Asjylyn Loder, "Shakeout Threatens Shale Patch as Frackers Go for Broke," *Bloomberg*, May 27, 2014, https://www.bloomberg.com/news/articles/2014-05-26/shakeout-threatens-shale-patch-as-frackers-go-for-broke.
[2351] Jonathan Fahey, "AP IMPACT: Deadly Side Effect to Fracking Boom," *Associated Press*, May 5, 2014, sec. Archive, https://apnews.com/article/ac54bee4225241729f360adbbcf394dd.
[2352] Elisabeth N. Radow, "At the Intersection of Wall Street and Main: Impacts of Hydraulic Fracturing on Residential Property Interests, Risk Allocation, and Implications for the Secondary Mortgage Market," *Albany Law Review* 77, no. 2 (2014): 673–704.
[2353] Multi-State Shale Research Collaborative, "Assessing the Impacts of Shale Drilling County Case Studies," April 10, 2014, https://docs.google.com/viewer?a=v&pid=sites&srcid=ZGVmYXVsdGRvbWFpbnxtdWx0aXN0YXRlc2hhbGV8Z3g6NGU4MjIyNWU5ZjFhZjM4Yg.

estimated for New York by the New York State Department of Environmental Conservation (NYS DEC).[2354, 2355]

- February 15, 2014 – The *Los Angeles Times* detailed steep increases in crime that have accompanied fracking in parts of the Eagle Ford Shale in Texas, including sexual assaults and thefts.[2356]

- February 14, 2014 – Pennsylvania landowners with fracking leases rallied in Bradford County against gas companies for precipitous drops in royalty payments.[2357]

- December 20, 2013 – The National Association of Realtors' *RealtorMag* summarized a growing body of research, including a University of Denver survey and a *Reuters* analysis, that shows threats property values from fracking and gas drilling.[2358]

- December 12, 2013 – A *Reuters* analysis discussed how oil and gas drilling has made making some properties "unsellable" and researched the link between drilling and property value declines. The analysis highlighted a Duke University working paper that finds shale gas drilling near homes can decrease property values by an average of 16.7 percent if the house depends on well water.[2359]

- December 10, 2013 – Pennsylvania's *Daily Review* reported that more gas companies are shifting costs to leaseholders and that royalty payments are drastically shrinking. The story quoted Bradford County Commissioner Doug McLinko saying that some gas companies "are robbing our landowners" and that the problem of royalty payments being significantly reduced by deductions for post-production costs "is widespread throughout our county."[2360]

- November 30, 2013 – The *New York Times* reported striking increases in crime in Montana and North Dakota where the oil and gas boom is prevalent, as well as challenges faced by local residents from the influx of out-of-area workers and the accompanying

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[2354] Marie Cusick, "Report Finds Each Marcellus Gas Well Costs Thousands in Road Damage," *State Impact Pennsylvania*, March 27, 2014, https://stateimpact.npr.org/pennsylvania/2014/03/27/report-finds-each-marcellus-gas-well-costs-thousands-in-road-damage/.
[2355] Shmuel Abramzon et al., "Estimating the Consumptive Use Costs of Shale Natural Gas Extraction on Pennsylvania Roadways," *Journal of Infrastructure Systems* 20, no. 3 (2014): 06014001, https://doi.org/10.1061/(ASCE)IS.1943-555X.0000203.
[2356] Molly Hennessy-Fiske, "Fracking Brings Oil Boom to South Texas Town, for a Price," *Los Angeles Times*, February 15, 2014, sec. World & Nation, https://www.latimes.com/nation/la-na-texas-oil-boom-20140216-story.html.
[2357] J. Marshall, "Landowners Rally for Royalties from Gas Companies," *WBNG*, February 14, 2014, http://www.wbng.com/news/local/Landowners-rally-for-245596511.html.
[2358] Daily Real Estate News, "'Fracking' Sparks Concern over Nearby Home Values," December 20, 2013, https://web.archive.org/web/20201105141321/https://magazine.realtor/daily-news/2013/12/20/fracking-sparks-concern-over-nearby-home-values.
[2359] Michelle Conlin, "Gas Drilling Is Killing Property Values For Some Americans," *Business Insider*, December 12, 2013, https://www.businessinsider.com/drilling-can-make-some-properties-unsellable-2013-12.
[2360] J. Loewenstein, "Shrinking Royalty Checks," *The Daily Review*, December 10, 2013, http://thedailyreview.com/news/shrinking-royalty-checks-1.1598195.

costs. The *New York Times* reported, "'It just feels like the modern-day Wild West,' said Sgt. Kylan Klauzer, an investigator in Dickinson, in western North Dakota. The Dickinson police handled 41 violent crimes last year, up from seven only five years ago."[2361]

- November 21, 2013 – The Multi-State Shale Research Collaborative released a six-state collaborative report demonstrating that the oil and gas industry has greatly exaggerated the number of jobs created by drilling and fracking in shale formations. The report found that far from the industry's claims of 31 direct jobs created per well, only four jobs are created for each well. It also demonstrated that almost all of the hundreds of thousands of 'ancillary' jobs that the drilling industry claims are related to shale drilling existed before such drilling occurred. As Frank Mauro, Executive Director Emeritus of the Fiscal Policy Institute put it, "Industry supporters have exaggerated the jobs impact in order to minimize or avoid altogether taxation, regulation, and even careful examination of shale drilling."[2362]

- November 12, 2013 – *The American Banker* reported that the "Fracking Boom Gives Banks Mortgage Headaches," with a number of financial institutions refusing to make mortgages on land where oil and gas rights have been sold to an energy company. The article stated that the uniform New York state mortgage agreement used by Fannie Mae and Freddie Mac requires that homeowners not permit any hazardous materials to be used or located on their property. Fracking is therefore a problem because it is just such a hazardous activity with use of hazardous materials.[2363]

- September 25, 2013 – A report found that fracking is linked to significant road damage, increased truck traffic, crime, and strain on municipal and social services. Data from the past ten years on the social costs of fracking including truck accidents, arrests, and higher rates of sexually transmitted diseases are all causes for alarm.[2364]

- September 12, 2013 – In a feature titled "Pa. fracking boom goes bust," *The Philadelphia Inquirer* presented data from the independent Keystone Research Center detailing "flat at best" job growth and declines in production and royalty payments.[2365]

[2361] Jack Healy, "As Oil Floods Plains Towns, Crime Pours In," *The New York Times*, November 30, 2013, https://www.nytimes.com/2013/12/01/us/as-oil-floods-plains-towns-crime-pours-in.html?smid=tw-share&_r=0.
[2362] Jon Campbell, "Report: Industry-Backed Studies Exaggerate Fracking Job Estimates," *Democrat and Chronicle*, November 21, 2013, https://www.democratandchronicle.com/story/news/local/2013/11/21/report-industry-backed-studies-exaggerate-fracking-job-estimates/3671199/.
[2363] Andy Peters, "Fracking Boom Gives Banks Mortgage Headaches," *American Banker*, November 12, 2013, https://www.americanbanker.com/news/fracking-boom-gives-banks-mortgage-headaches.
[2364] Brendan S. Gibbons, "Environmental Groups Calculate Social Cost of Natural Gas Boom," *The Times-Tribune*, September 25, 2013, https://www.thetimes-tribune.com/archive/environmental-groups-calculate-social-cost-of-natural-gas-boom/article_a6f11ae0-77d7-5fe1-ac25-a4ec8dd6cd06.html.
[2365] Will Bunch, "Pa. Fracking Boom Goes Bust," *The Philadelphia Inquirer*, November 12, 2013, https://www.inquirer.com/philly/hp/news_update/20130911_Pa__fracking_boom_goes_bust.html.

- August 22, 2013 – A University of Denver study in the *Journal of Real Estate Literature* found a 5-15 percent reduction in bid value for homes near gas drilling sites.[2366]

- August 21, 2013 – *The Atlantic Cities* and *MSN Money* reported that fracking operations may be damaging property values and may impair mortgages or the ability to obtain property insurance.[2367, 2368]

- August 13, 2013 – A *ProPublica* investigative analysis found that Chesapeake Energy is coping with its financial difficulties in Pennsylvania by shifting costs to landowners who are now receiving drastically reduced royalty payments.[2369]

- August 4, 2013 – In a survey of West Virginia landowners with shale wells on their property, more than half reported problems including damage to the land, decline in property values, truck traffic, and lack of compensation by the oil and gas company.[2370]

- May 24, 2013 – Pennsylvania Department of Transportation Secretary Allen D. Biuhler and Pennsylvania State Police Commissioner Frank Pawlowski said that gas drilling has led to increases in truck traffic, traffic violations, crime, demand for social services, and the number of miles of roads that are in need of repairs. They noted that drilling companies that committed to repairing roads have not kept pace with the roads they damage. Commissioner Pawlowski reported that 56 percent of 194 trucks checked were over the legal weight limit and 50 percent were also cited for safety violations.[2371]

- May 4, 2013 – Pennsylvania's *Beaver County Times* asked, "What boom?" in pointing to Keystone Research Center data showing that the number of jobs numbers created by shale gas extraction do not add up to what the gas industry claims, noting that unemployment has increased and the state actually fell to 49th in the nation for job creation.[2372]

[2366] Bob Downing, "Survey Says Home Values Hurt by Fracking at Drill Sites," *Akron Beacon Journal*, April 22, 2013, https://web.archive.org/web/20140326041052/http://www.ohio.com/blogs/drilling/ohio-utica-shale-1.291290/survey-says-home-values-hurt-by-fracking-at-drill-sites-1.422838.
[2367] Roger Drouin, "How the Fracking Boom Could Lead to a Housing Bust," *CityLab*, August 19, 2013, https://www.bloomberg.com/news/articles/2013-08-19/how-the-fracking-boom-could-lead-to-a-housing-bust.
[2368] Jason Notte, "Fracking Leaves Property Values Tapped Out," *Concerned Burlington Neighbors* (blog), August 21, 2013, http://concernedburlingtonneighbors.blogspot.com/2013/08/.
[2369] Abrahm Lustgarten, "Unfair Share: How Oil and Gas Drillers Avoid Paying Royalties," *ProPublica*, August 13, 2013, https://www.propublica.org/article/unfair-share-how-oil-and-gas-drillers-avoid-paying-royalties.
[2370] Alan R. Collins and Kofi Nkansah, "Divided Rights, Expanded Conflict: The Impact of Split Estates in Natural Gas Production," Scholarly Project (Natural Resource Economics, West Virginia University, August 4, 2013), https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.734.6591&rep=rep1&type=pdf.
[2371] PR News Wire, "Increased Gas Drilling Activities Bringing New Challenges to Local Governments in Pennsylvania," *PR Newswire*, May 24, 2010, https://www.prnewswire.com/news-releases/increased-gas-drilling-activities-bringing-new-challenges-to-local-governments-in-pennsylvania-94774764.html.
[2372] Rachel Morgan, "Beaver County Times: What Boom? Industry Pundits Claim Thousands of Jobs Will Be Created, but Numbers Don't Quite Add up," *Keystone Research Center*, May 4, 2013, https://web.archive.org/web/20131010021511/http://keystoneresearch.org/media-center/media-coverage/beaver-county-times-what-boom-industry-pundits-claim-thousands-jobs-will.

- April 2, 2013 – The *New York Times* reported that manufacturing jobs resulting from an abundance of shale gas have not appeared. "The promised job gains, other than in the petrochemical industry, have been slow to materialize," The *New York Times* reported. The article suggested that increased automation has made it unlikely that manufacturers will add many jobs.[2373]

- March 19, 2013 – The *Wall Street Journal* reported that the shale gas boom has not had a big impact on U.S. manufacturing because lower energy prices are only one factor in a company's decision on where to locate factories, and not always the most important factor. "Cheap energy flowing from the U.S. shale-gas boom is often touted as a 'game changer' for manufacturing," the *Journal* reported. "Despite the benefits of lower energy costs, however, the game hasn't changed for most American manufacturers."[2374]

- February 2013 – A peer-reviewed analysis of industry-funded and independent studies on the economics of fracking found that it is unlikely that fracking will lead to long-term economic prosperity for communities. The analysis noted that shale gas development brings a number of negative externalities including the potential for water, air, and land contamination; negative impacts on public health; wear and tear on roads and other infrastructure; and costs to communities due to increased demand for services such as police, fire departments, emergency responders, and hospitals.[2375]

- November 16, 2012 – A Duke University study showed a drop in home values near fracking for properties that rely on groundwater.[2376]

- September 27, 2012 – The *New York Times* reported that the prospect of fracking has hindered home sales in the Catskills and raised concerns about drops in property values, according to real estate agents and would-be buyers.[2377]

- August 17, 2012 – A study by the state agencies, the Montana All Threat Intelligence Center and the North Dakota State and Local Intelligence Center, found that crime rose by 32 percent since 2005 in communities at the center of the oil and gas boom.[2378]

[2373] Nelson D. Schwartz, "Rumors of a Cheap-Energy Jobs Boom Remain Just That," *The New York Times*, April 1, 2013, sec. Business, https://www.nytimes.com/2013/04/02/business/economy/rumors-of-a-cheap-energy-jobs-boom-remain-just-that.html.
[2374] James R. Hagerty, "Shale-Gas Boom Alone Won't Propel U.S. Industry," *Wall Street Journal*, March 19, 2013, sec. Business, https://online.wsj.com/article/SB10001424127887324392804578362781776519720.html.
[2375] Jannette M. Barth, "The Economic Impact of Shale Gas Development on State and Local Economies: Benefits, Costs, and Uncertainties," *New Solutions* 23, no. 1 (2013): 85–101, https://doi.org/10.2190/NS.23.1.f.
[2376] Danielle Muoio, "Duke Researchers Show Dip in Home Value Caused by Nearby Fracking," *The Chronicle*, November 16, 2012, https://www.dukechronicle.com/article/2012/11/duke-researchers-show-dip-home-value-caused-nearby-fracking.
[2377] Mireya Navarro, "Gas Drilling Jitters Unsettle Catskills Sales," *The New York Times*, September 27, 2012, sec. Real Estate, https://www.nytimes.com/2012/09/30/realestate/fracking-fears-hurt-second-home-sales-in-catskills.html.
[2378] "Impact of Population Growth on Law Enforcement in the Williston Basin Region" (Montana All Threat Intelligence Center & North Dakota State and Local Intelligence enter, August 17, 2012).

- October 30, 2011 – A comprehensive article in the *New York State Bar Association Journal* concluded that the risks inherent with fracking threaten mortgages.[2379]

- October 26, 2011 – The Associated Press reported that areas with significant fracking activity, including Pennsylvania, Wyoming North Dakota and Texas, are "seeing a sharp increase in drunken driving, bar fights and other hell-raising."[2380]

- October 20, 2011 – A *New York Times* investigation found that fracking can create conflicts with mortgages, and that "bankers are concerned because many leases allow drillers to operate in ways that violate rules in landowners' mortgages," and further that "[f]earful of just such a possibility, some banks have become reluctant to grant mortgages on properties leased for gas drilling. At least eight local or national banks do not typically issue mortgages on such properties, lenders say."[2381]

- September 7, 2011 – The NYS DEC estimated that 77 percent of the workforce on initial shale gas drilling projects would consist of transient workers from out of state. Not until the thirtieth year of shale gas development would 90 percent of the workforce be comprised of New York residents.[2382]

- August 15, 2011 – The *Pittsburgh Post-Gazette* reported that increases in crime followed the Pennsylvania gas drilling boom, noting, for instance, that drunken driving arrests in Bradford County were up 60 percent, DUI arrests were up 50 percent in Towanda, and criminal sentencing was up 35 percent in 2010.[2383]

- July 26, 2011 – A New York State Department of Transportation document estimated that fracking in New York could result in the need for road repairs and reconstruction costing $211 million to $378 million each year.[2384]

- June 20, 2011 – A Keystone Research Center study found that the gas industry's claim of 48,000 jobs created between 2007 and 2010 as a result of natural gas drilling in

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[2379] Elisabeth N. Radow, "Homeowners and Gas Drilling Leases: Boon or Bust?," *New York State Bar Association* 83, no. 9 (2011), https://planetwaves.net/pdf/fracking.pdf.
[2380] Mark Levy, "Towns See Crime, Carousing Surge amid Gas Boom," *The San Diego Union-Tribune*, October 26, 2011, https://www.sandiegouniontribune.com/sdut-towns-see-crime-carousing-surge-amid-gas-boom-2011oct26-story.html.
[2381] Ian Urbina, "Rush to Drill for Natural Gas Creates Conflicts With Mortgages," *The New York Times*, October 20, 2011, sec. U.S., https://www.nytimes.com/2011/10/20/us/rush-to-drill-for-gas-creates-mortgage-conflicts.html.
[2382] New York State Department of Environmental Conservation, "Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program, Well Permit Issuance for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs," 2011.
[2383] Zack Needles, "Must Crime Follow Pennsylvania's Gas Drilling Boom?," *Pittsburgh Post-Gazette*, August 15, 2011, https://www.post-gazette.com/business/legal/2011/08/15/Must-crime-follow-Pennsylvania-s-gas-drilling-boom/stories/201108150204.
[2384] S. Reilly, "Document Estimates Fracking's Toll on N.Y. Roads," *Pressconnects.Com*, July 26, 2011, http://www.pressconnects.com/article/20110726/NEWS01/107260384/Document-estimates-fracking-s-toll-N-Y-roads.

Pennsylvania is a far cry from the actual number of only 5,669 jobs—many of which were out-of-state hires.[2385]

- May 9, 2011 – A study in the *Journal of Town & City Management* found that shale gas development can impose "significant short- and long-term costs" to local communities. The study noted that shale gas development creates a wide range of potential environmental hazards and stressors, all of which can adversely impact regional economies, including tourism and agriculture sectors.[2386]

- November 30, 2010 – The *Dallas Morning News* featured a story, "Drilling Can Dig into Land Value," reporting that the Wise County Central Appraisal District Appraisal Review Board found that a drilling company had caused an "extraordinary reduction" in property value, by 75 percent.[2387]

- November 28, 2010 – The Texas *Wise County Messenger* reported that some landowners near fracking operations experience excessive noise, exposure to diesel fumes, and problems with trespassing by workers.[2388]

[2385] Stephen Herzenberg, "Drilling Deeper into Job Claims" (Keystone Research Center, 2011), http://keystoneresearch.org/sites/keystoneresearch.org/files/Drilling-Deeper-into-Jobs-Claims-6-20-2011_0.pdf.
[2386] Susan Christopherson and Ned Rightor, "How Shale Gas Extraction Affects Drilling Localities: Lessons for Regional and City Policy Makers," *Journal of Town & City Management* 2, no. 4 (2012), http://greenchoices.cornell.edu/resources/publications/drilling/Effects_on_Drilling_Localities.pdf.
[2387] Peggy Heinkel-Wolfe, "Drilling Can Dig into Land Value," *Dallas News*, September 18, 2010, https://web.archive.org/web/20120323152358/http://www.dallasnews.com/incoming/20100918-Drilling-can-dig-into-land-value-9345.ece.
[2388] Brandon Evans, "Rising Volume: 'Fracking' Has Bolstered Economies, but Noise Still Echoes around Drilling," *WC Messenger*, November 28, 2010, https://web.archive.org/web/20110603152315/http://www.wcmessenger.com/2010/news/rising-volume-fracking-has-bolstered-economies-but-noise-still-echoes-around-drilling/.

Inflated estimates of oil and gas reserves, profitability problems, and risk disclosure to investors

Industry projections of shale-based oil and gas reserves have proven undependable and unable to forecast how much oil or gas can be extracted from a given basin based on the production of existing wells. Further, unlike conventional wells, which can provide steady yields for decades, fracked wells typically deplete 70-90 percent within three years, requiring more drilling and continuous capital investment. Low yields and heavy extraction costs have led companies drilling shale to reduce the value of their assets by billions of dollars, creating shortfalls that are largely filled through asset sales and mounting debt load. Throughout the fracking boom, the industry as a whole has spent more money drilling wells than selling oil and gas and remained dependent on cheap credit and low interest rates. Fracking has never been consistently profitable, despite being heavily subsidized through tax incentives that have functioned to encourage continuing investments even when gas and oil prices are low.

In 2014, a fall in oil and gas prices led to a two-year downturn in fracking operations and a wave of bankruptcies. When companies abandoned operations, they also abandoned the wells they drilled, raising questions about who serves as the custodian of inactive wells and their associated infrastructure, now and hereafter. Bonding requirements proved—and still are—notoriously inadequate.

A modest upswing in prices in 2017 brought renewed industry enthusiasm for fracking. However, because of the rapid depletion of individual shale wells and the falling output of major shale basins, operators invested in drilling new wells at an increasingly rapid pace to maintain the same level of extraction. More than half of all U.S. oil was extracted from wells that were two years old or younger, and they pumped less oil than forecast. Despite rising oil prices, fracking-focused companies continued to lose cash. By 2018, the need to stabilize economic fundamentals by increasing production and lowering costs contributed to the shift toward mega-fracking—with ever-longer laterals and higher volumes of water, sand, and chemicals per well—and also toward the practice of clustering many secondary wells near a productive parent well. The act of fracking these so-called child wells, however, often permanently damages the primary wells they surround, undermining production in the whole area.

In 2020, oil and gas prices collapsed under suddenly constricted demand during the COVID-19 pandemic, oversupply in the global markets, and a price war between Russia and Saudi Arabia. By April 2020, oil futures had fallen to levels below the break-even point for fracking operations, triggering a wave of bankruptcies. Decisions by major investors to divest from fossil fuel projects followed. By 2021, under investor pressure to turn profits and slash carbon emissions, oil and gas majors began selling off fracking assets to smaller, independent companies. As a group, however, these companies are among the biggest methane emitters in the industry. By 2023, pressure from investors to increase dividends had suppressed capital expenditures and productivity. A shift to higher prices and a solution to the ongoing labor crisis within the oil and gas industry would be required for fracking companies to expand aggressively.

- June 1, 2023 – Over objections that the oil and gas industry should fund its own fracking activities, North Dakota legislature passed a bill, signed by the governor, that incentivizes fracking by reducing the oil extraction tax on wells that are re-stimulated. The law went into effect on July 1, 2023.[2389]

- January 12, 2023 – An investigation by the Ohio River Valley Institute into Diversified Energy's financial practices revealed that the company has likely not set aside sufficient funds for decommissioning its inventory of more than 72,000 wells in Appalachia. Eschewing industry standards in accounting for its obligations to pay for plugging its wells once they are no longer productive, Diversified assumes in its financial statements that it can plug wells at an average cost of $21,000, a fraction of industry norms, and also assumes that its wells will remain productive for the next 73 years. Diversified's estimates of its own costs to decommission wells are also questionable because they are only a fraction of what the company charges states when it is hired to plug orphaned wells using federal funds. "For example, the company has been awarded a contract to plug and abandon 100 wells in West Virginia, at an average cost per well of $126,000. Yet it claims in its financial filings that it can plug and abandon its own wells for roughly one sixth the cost it will be paid with federal dollars."[2390]

- August 17, 2022 – The U.S. fracking boom allowed crude oil production per active well to more than double from 2011 to 2019, while gas production per well jumped 50 percent over the same time period. However, economic profits declined over this same period, with persistent losses setting in after 2014. This disconnect between productivity and profits in U.S. oil and gas extraction created pressure from investors to increase dividends and pay down debt at the expense of capital expansion. Going forward, a shift to higher prices would be required for fracking companies to expand production aggressively, according to an analysis by the Federal Reserve Bank of New York.[2391]

- June 23, 2021 – A study from the Stockholm Environment Institute, a nonprofit research center, examined how U.S. federal policy in the form of powerful tax incentives has created an indirect subsidy to the fracking industry throughout the past two decades. These tax breaks reduce the risks of investing and amplify the expected financial returns of investing in fracking operations, thereby aiding and sustaining the U.S. shale boom. The expensing of intangible drilling costs and percentage depletion provisions, for example, work to reduce tax payments and increase the expected value of new oil and gas wells by up to $20 billion in a single year. Among other specific findings: between 2007 and 2014, when oil prices were high (above $60/barrel), subsidies had relatively little

[2389] North Dakota Office of Tax Commissioner, "2023 Legislative Recap," North Dakota Wholesale & Oil Taxes Newsletter, June 2023, https://www.tax.nd.gov/sites/www/files/documents/newsletters/2023-wholesale-and-oil-taxes-newsletter.pdf.
[2390] Ted Boettner and Kathy Hipple, "Diversified Energy's Questionable Financial Practices Continue in 2022" (Ohio River Valley Institute, January 12, 2023), https://ohiorivervalleyinstitute.org/diversified-energys-questionable-financial-practices-continue-in-2022/.
[2391] Matthew Higgins and Thomas Klitgaard, "The Disconnect between Productivity and Profits in U.S. Oil and Gas Extraction," Liberty Street Economics (Federal Reserve Bank of New York, August 17, 2022), https://libertystreeteconomics.newyorkfed.org/2022/08/the-disconnect-between-productivity-and-profits-in-u-s-oil-and-gas-extraction/.

effect on decisions to drill. But in low-price years, "subsidies increased expected returns enough to push more than 30 percent of new oil projects into profitability, greenlighting their investment decisions." Further, subsidies likely played a substantial role in abetting the fracking boom in Appalachia, "making new gas projects viable, beginning in 2010, when more than 30 percent of new gas projects may have been subsidy-dependent." This study illustrates that tax code is a powerful policy tool, able to influence what energy projects get developed.[2392]

- June 14, 2021 – Small, independent drilling and fracking companies backed by private equity are disproportionately represented among the highest emitters of methane, according to a report based on industry data submitted to the U.S. Environmental Protection Agency. These 195 small producers together account for 9 percent of production but contribute 22 percent of total reported emissions. "The study also reinforces concerns that oil firms 'greening up' by selling assets does little to help the climate when the emissions are just transferred to another operator that may be less environmentally minded."[2393]

- May 26, 2021 – A group of investors, backed by three large pension funds, installed new board members at ExxonMobil over the objection of the company's management. The new investors want ExxonMobil to pledge to reduce its emissions to net zero by 2050, warning that an emissions reduction strategy was a fundamental investor issue given the immense risk to ExxonMobil's current business model and flagging financial performance. "Investors are no longer standing on the sidelines."[2394]

- May 26, 2021 – The Hague District Court ordered Royal Dutch Shell to cut carbon emissions by 45 percent by 2030, in line with United Nations guidance for member states to limit global warming to 1.5° Celsius above pre-industrial levels. This is the first ruling in the Netherlands of a non-State entity being ordered to reduce carbon dioxide emissions, a ruling which can potentially pave the way for further litigation against other emitters in and outside of the Netherlands.[2395]

- May 18, 2021 – The International Energy Agency, an intergovernmental energy policy advisor to 30 different member nations and other emerging economies, called in a major report for no new investments in fossil fuels as part of a plan to achieve to net-zero

[2392] Peter Erickson and Ploy Achakulwisut, "How Subsidies Aided the US Shale Oil and Gas Boom" (Stockholm Environment Institute, June 23, 2021), https://www.sei.org/publications/subsidies-shale-oil-and-gas/.
[2393] Stephen Cunningham, "Private Equity-Backed Drillers Under Emissions Scrutiny," Argus, June 14, 2021, https://www.argusmedia.com/en/news/2224429-private-equitybacked-drillers-under-emissions-scrutiny?backToResults=true.
[2394] Stephen Cunningham, "Exxon Humbled by Shareholder Revolt: Update," Argus, May 26, 2021, https://www.argusmedia.com/en/news/2218876-exxon-humbled-by-shareholder-revolt-update.
[2395] "Climate Change Litigation Bombshell: Dutch Lower Court Orders Royal Dutch Shell to Reduce CO2 Emissions," Jonesday.com, May 26, 2021, https://www.jonesday.com/en/insights/2021/06/climate-change-litigation-bombshell-dutch-lower-court-orders-royal-dutch-shell-to-reduce-co2-emissions.

emissions by 2050. The plan also calls for retiring coal plants by 2030 and banning sales of new internal combustion engine cars by 2035.[2396]

- April 30, 2021 – The first study to fully assess the inadequacies of New Mexico's oil and gas bonding requirements on both state and private lands found a $8.18 billion gap between the bonds posted for in the state ($201.42 million) and the projected costs of cleaning up the sites should companies declare bankruptcy ($8.38 billion). The study also found that no bonding requirements exist for many of the ancillary pieces of drilling-related infrastructure, including compressor station sites, fracking waste pits, storage facilities, and warehouses.[2397] This study was based on publicly available data as well as data provided to researchers by the New Mexico State Land Office. However, the authors emphasize that their analysis was limited by lack of transparency. "For instance, we did not have access to a full report on the financial assurance carried by operators permitted by the New Mexico Oil Conservation Division, and therefore we had to use sampling techniques to build a reasonable estimate."[2398]

- March 9, 2021 – A joint analysis by the Stockholm Environment Institute and the Ohio River Valley Institute looked at the major drivers of demand for natural gas and found financial risks for expanding natural gas extraction in Appalachia, including for new gas wells, pipelines, and export terminals. Analysts predicted that decreased global demand and robust competition from renewables will ultimately render new fracking operations in the region, which includes Ohio, West Virginia, and Pennsylvania, unprofitable.[2399]

- February 9, 2021 – Chesapeake Energy, once the United States' second-largest natural gas producer, emerged from bankruptcy with a business plan that signals a shift back to fracking for natural gas—with a focus on Louisiana and Appalachia—and away from oil extraction. Chesapeake filed for court protection in June 2020 and won approval, six months later, for a plan that allowed it to shed about $7.7 billion in debt. Chesapeake was unable to turn a profit while simultaneously paying down $9 billion in debt. To complete its exit from bankruptcy, Chesapeake took on $1 billion in new debt and dismissed 15 percent of its workforce. "We were never able to invest in our assets to the benefit of our shareholders," said Chief Executive Doug Lawler in an interview with Reuters.[2400]

[2396] International Energy Agency, "Net Zero by 2050: A Roadmap for the Global Energy Sector, 3rd Revision," May 2021, https://www.iea.org/reports/net-zero-by-2050.
[2397] The Center for Applied Research, Inc., "An Analysis of the Adequacy of Financial Assurance Requirements for Oil and Gas Infrastructure Located on State Trust and Private Lands In New Mexico" (The Center for Applied Research, Inc., April 30, 2021), https://www.nmstatelands.org/wp-content/uploads/2021/05/NM-Assurance-Assessment-May-FINAL.pdf.
[2398] Hannah Grover, "Analysis Finds $8.1 Billion Gap in New Mexico Bonding Requirements, Clean Up Costs for Oil and Gas," *NM Political Report*, May 20, 2021, https://nmpoliticalreport.com/2021/05/20/analysis-finds-8-1-billion-gap-in-new-mexico-bonding-requirements-clean-up-costs-for-oil-and-gas/.
[2399] Peter Erickson and Ploy Achakulwisut, "Risks for New Natural Gas Developments in Appalachia" (Stockholm Environment Institute U.S. and Ohio River Valley Institute, March 2021), https://cdn.sei.org/wp-content/uploads/2021/03/risks-of-new-natural-gas-developments-in-appalachia-march-2021-final-3.9.21.pdf.
[2400] Jennifer Hiller, "Chesapeake Energy Emerges from Bankruptcy and Shifts Back to Natural Gas," February 2, 2021, https://www.reuters.com/article/us-chesapeake-energy-bankruptcy/chesapeake-energy-emerges-from-bankruptcy-and-shifts-back-to-natural-gas-

- February 1, 2021 – S&P Global Ratings downgraded the credit ratings of Exxon Mobil Corp, Chevron Corp and ConocoPhillips, citing poor financial performance and pressure to act on climate change. Weeks earlier, the agency had warned it was considering downgrades for 13 of the world's largest oil companies due to rising risk from energy transition and price volatility.[2401]

- January 21, 2021 – The president of the European Investment Bank, Werner Hoyer, announced that the bank is phasing out funding for fossil fuel projects and intends to pursue a decarbonization policy that aligns with the goals of the Paris Climate Agreement. "To put it mildly, gas is over. This is a serious departure from the past, but without the end to the use of unabated fossil fuels, we will not be able to reach the climate targets."[2402]

- January, 2021 – Providing 38.2 percent of Europe's electricity, renewable energy surpassed fossil fuels in the European power sector in 2020, jumping by four percent over its 2019 contribution. The use of fossil fuels for power generation declined in the years 2010-2020 from 49 percent to 37 percent, with coal falling fastest.[2403]

- October 2, 2020 – Credit rating agency Moody's announced that long-term credit risks for natural gas infrastructure projects are rising, as the increasing public focus on decarbonization threatens to reduce demand for natural gas. Moody's cited obstacles to pipeline permitting and construction, rising capital costs, and climate goals, in addition to methane emissions and rising safety concerns.[2404]

- July 22, 2020 – An analysis of energy return on investment showed that the fracking industry has consumed an ever-larger portion of the energy it extracts as the shale basins become exhausted and the energy infrastructure is forced to expand and absorb more GDP. Further, because fracked wells typically deplete 70-90 percent within three years, fracking incurs heavy extraction costs and continuous capital investment. The advent of the fracking boom itself, which corresponds to the economic downturn in 2008, was made possible by historically low interest rates and continues to depend on cheap credit. Driven by fracking, the fossil fuel economy suffers from an inability to sustain economic

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[2401] Reuters Staff, "S&P Downgrades Exxon and Chevron on Climate Risk, Dour Earnings," Reuters, February 12, 2021, https://www.reuters.com/article/us-usa-oil-credit/sp-downgrades-exxon-and-chevron-on-climate-risk-dour-earnings-idUSKBN2AC29C.

[2402] "'Gas Is over', EU Bank Chief Says," *Euractiv*, January 21, 2021, https://www.euractiv.com/section/energy-environment/news/gas-is-over-eu-bank-chief-says//.

[2403] Agora Energiewende and Ember, "The European Power Sector in 2020: Up-to-Date Analysis on the Electricity Transition," January 2021, https://ember-climate.org/wp-content/uploads/2021/01/Report-European-Power-Sector-in-2020.pdf.

[2404] Tom DiChristopher, "Moody's: Long-Term Credit Risks Are Rising for Natural Gas Infrastructure Projects," IEEFA.org, October 2, 2020, https://ieefa.org/moodys-long-term-credit-risks-are-rising-for-natural-gas-infrastructure-projects/.

growth as the energy return on investment is lower with fracking than it was for conventional fossil fuels. This article concludes that the United States' increasing reliance on fracking to obtain energy is not sustainable. "On the one hand, this will lead to 'energy sprawl'—the growth of the energy sector, as this sector consumes a much larger portion of the energy it extracts—leaving less energy surplus for other sectors. On the other hand, we will see an unsustainable imbalance between the fuel prices that fossil-fuel companies will need to meet their costs and the fuel prices that the larger economy can afford to pay."[2405]

- July 7, 2020 – The energy media outlet *Energy Review* reported that the collapse in the global gas market has jeopardized the future of capital-intense LNG export projects, which were driven by the U.S. fracking boom. Even as spending on new gas terminals to ship LNG abroad has doubled since 2019, these projects are at risk of being abandoned because of a global glut of fossil fuels. At least two dozen such projects are already canceled or facing serious financial difficulties. These problems have been made worse by the pandemic but are not expected to resolve when the pandemic ends due to other underlying trends. Other nations have adopted renewable energy technology sooner than expected, and some large investors, including the European Investment Bank, have stopped funding fossil fuel projects altogether as it becomes clear that any new gas infrastructure places the goals of the Paris Climate Accord out of reach.[2406]

- June 28, 2020 – Fracking giant Chesapeake Energy said that it had filed for bankruptcy protection. Once the nation's second-largest gas producer, Chesapeake was beset by debt and deeply harmed by the downturn in oil and gas prices in the wake of the coronavirus pandemic. Owing $9 billion to lenders, Chesapeake entered an agreement to cut $7 billion of its debt.[2407, 2408]

- June 17, 2020 – Goldman Sachs Group reports that investment in renewable energy is expected to overtake oil and gas investment in 2021, representing a $16 trillion investment opportunity in the coming decade. This trend is driven in part by a diverging cost of capital, as borrowing rates have risen as high as 20 percent for hydrocarbon projects compared with as little as 3 percent for clean energy.[2409]

[2405] Bart Hawkins Kreps, "The Rising Costs of Fossil-Fuel Extraction: An Energy Crisis That Will Not Go Away," *American Journal of Economics and Sociology* 79, no. 3 (2020): 695–717, https://doi.org/10.1111/ajes.12336.
[2406] "Gas Projects in Jeopardy as Global Market Collapses," *Energy Review*, July 7, 2020, https://energyreviewmena.com/index.php/article/oil-gas/item/813-gas-projects-in-jeopardy-as-global-market-collapses.
[2407] Cathy Bussewitz and Tali Arbel, "Fracking Pioneer Chesapeake Energy Files for Bankruptcy Protection," *USA Today*, June 28, 2020, https://www.usatoday.com/story/money/2020/06/28/plunging-oil-prices-send-chesapeake-into-bankruptcy/3275712001/.
[2408] Clifford Krauss, "Chesapeake Energy, a Fracking Pioneer, Is Reeling," *The New York Times*, June 9, 2020, sec. Business, https://www.nytimes.com/2020/06/09/business/energy-environment/chesapeake-energy-bankruptcy-protection.html.
[2409] Dan Murtaugh, "Goldman Sachs Sees $16 Trillion Investment Opportunity in Renewable Energy Through 2030," IEEFA.org, June 17, 2020, https://ieefa.org/goldman-sachs-sees-16-trillion-investment-opportunity-in-renewable-energy-through-2030/.

- April 24, 2020 – The largest oil producer in North Dakota, Continental Resources, stopped all drilling in the state and shut in most of its wells as another major player the Bakken Shale, Whiting Petroleum, filed for bankruptcy.[2410]

- April 19, 2020 – U.S. oil prices fell into negative numbers as demand for crude oil plummeted and created a supply glut that filled storage facilities, including tanker vessels anchored at sea. U.S. crude futures fell to levels well below the break-even costs for fracking operations, leading to a wave of drilling halts. Fracking service company Halliburton reported a $1 billion loss during its first quarter.[2411]

- April 10, 2020 – In a financial analysis of U.S. fracking operations, journalist Bethany McLean argued that the willingness of investors to continue buying debt at super-low interest rates has served as a financial lifeline to the fracking industry for the past decade. "They have subprimed the American energy ecosystem." As debt markets grew more cautious, fracking was propped up by private equity investors. "In the Haynesville and the Utica Shales, two major natural gas plays, over half of the drilling is being done by private equity-backed companies; in the oil-rich Permian Basin, it's about a quarter of the drilling. From 2015 through 2019, private equity firms raised almost $80 billion in funds focused mostly on shale production…. Energy independence was a fever dream, fed by cheap debt and frothy capital markets."[2412]

- April 1, 2020 – U.S. fracking company Whiting Petroleum announced it had filed for bankruptcy protection.[2413]

- March 11, 2020 – U.S. fracking company Occidental Petroleum announced it had cut dividends to investors for the first time in 30 years due to a sharp decline in prices.[2414]

- December 23, 2019 – Banks that have helped fund the fracking boom have begun to tighten revolving lines of credit as they revise estimates on the value of shale reserves held as collateral.[2415]

- December 11, 2019 – Chevron announced that it would write down at least $10 billion in assets, mostly shale gas holdings in the Marcellus Shale and a planned LNG export

[2410] Devika Krishna Kumar and Liz Hampton, "U.S. Oil Firm Continental Resources Halts Shale Output, Seeks to Cancel Sales," *Reuters*, April 24, 2020, sec. Commodities, https://www.reuters.com/article/us-continental-resources-shale-north-dak-idUSKCN2260PX.
[2411] Stephanie Kelly, "Oil Price Crashes into Negative Territory for the First Time in History amid Pandemic," *Reuters*, April 19, 2020, sec. Commodities, https://www.reuters.com/article/us-global-oil-idUSKBN2210V9.
[2412] Bethany McLean, "Opinion | Coronavirus May Kill Our Fracking Fever Dream," *The New York Times*, April 10, 2020, sec. Opinion, https://www.nytimes.com/2020/04/10/opinion/sunday/coronavirus-texas-fracking-layoffs.html.
[2413] Collin Eaton and Andrew Scurria, "Whiting Petroleum Becomes First Major Shale Bankruptcy as Oil Prices Drop," *Wall Street Journal*, April 1, 2020, sec. Business, https://www.wsj.com/articles/u-s-shale-driller-whiting-petroleum-to-file-for-bankruptcy-11585746800.
[2414] "US Fracking Giant Feels Pain of Price Crash," *Energy Reporters*, March 11, 2020, https://www.energy-reporters.com/production/us-fracking-giant-feels-pain-of-price-crash/.
[2415] Christopher M. Matthews, Bradley Olson, and Allison Prang, "Banks Get Tough on Shale Loans as Fracking Forecasts Flop," *Wall Street Journal*, December 23, 2019, sec. Business, https://www.wsj.com/articles/banks-get-tough-on-shale-loans-as-fracking-forecasts-founder-11577010600.

facility in Canada, while EQT, also a major player in the Marcellus Shale, cut a quarter of its work force.[2416]

- August 20, 2019 – Using new methods involving water pyrolysis, a team of researchers at University of Nottingham estimated the amount of gas inside the Bowland Shale in the United Kingdom. Their findings showed dramatically less gas available for extraction by fracking than previous supposed. According to their results, the amount of gas available is the equivalent of five to seven years of gas, based on current rates of consumption in the United Kingdom. Previous estimates by the British Geological Survey had pegged the likely amount of gas as a 50-year supply.[2417, 2418]

- January 2, 2019 – An analysis by the *Wall Street Journal* comparing productivity estimates provided to investors with third-party projections revealed that thousands of shale wells are pumping considerably less oil and gas than owners were forecasting. Two-thirds of projections made by fracking companies between 2014-2017 in Texas and North Dakota oil basins were overly optimistic. All together, these companies are on track to extract 10 percent less oil and gas than they predicted. "The Journal's findings suggest current production levels may be hard to sustain without greater spending because operators will have to drill more wells to meet growth targets."[2419]

- October 17, 2018 – A research brief jointly published by the Institute for Energy Economics and Financial Analysis and the Sightline Institute tracked cash flow for 33 leading fracking companies. It found that fracking-focused companies continued to lose cash through the first half of 2018. Specifically, between January and June 2018, in spite of rising oil prices, fracking companies spent $3.9 billion more on drilling than they generated by selling oil and gas.[2420]

- September 20, 2018 – Confronted with falling prices and mounting debt, Southwest Energy sold off its assets in Arkansas' Fayetteville Shale, placing fracking on hold.[2421]

- June 4, 2018 – A macroeconomic study using a simulation model found that economies that depend on fossil fuel extraction could be gravely harmed if global demand for fossil

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[2416] Clifford Krauss, "Natural Gas Boom Fizzles as a U.S. Glut Sinks Profits," *The New York Times*, December 11, 2019, sec. Business, https://www.nytimes.com/2019/12/11/business/energy-environment/natural-gas-shale-chevron.html.
[2417] Patrick Whitelaw et al., "Shale Gas Reserve Evaluation by Laboratory Pyrolysis and Gas Holding Capacity Consistent with Field Data," *Nature Communications* 10, no. 1 (2019): 3659, https://doi.org/10.1038/s41467-019-11653-4.
[2418] Matt McGrath, "Fracking: UK Shale Reserves May Be Smaller than Previously Estimated - BBC News," *BBC News*, August 20, 2019, https://www.bbc.com/news/science-environment-49395658.
[2419] Bradley Olson, Rebecca Elliott, and Christopher M. Matthews, "Fracking's Secret Problem—Oil Wells Aren't Producing as Much as Forecast," *Wall Street Journal*, January 2, 2019, sec. Markets, https://www.wsj.com/articles/frackings-secret-problemoil-wells-arent-producing-as-much-as-forecast-11546450162.
[2420] Institute for Energy Economics and Financial Analysis, & Sightline Institute. (2018, October 17). *Energy market update: Red flags on U.S. fracking, disappointing financial performance continues.* Retrieved from http://ieefa.org/wp-content/uploads/2018/10/Red-Flags-on-U.S.-Fracking_October-2018.pdf
[2421] Daniel Breen, "Fayetteville Shale Assets Sold Off, Fracking Still On Hold," *Arkansas Public Media*, September 20, 2018, https://www.arkansaspublicmedia.org/post/fayetteville-shale-assets-sold-fracking-still-hold.

fuels declines in the face of innovations in energy efficiency and renewable technologies and public policy that promotes them. "Russia, the United States or Canada…could see their fossil fuel industries nearly shut down. ... The United States is worse off if it continues to promote fossil fuel production and consumption than if it moves away from them. This is due to the way global fossil fuel prices are formed. If the rest of the world reduces fossil fuel consumption and there is a sell-out, then lower fuel prices will make much US production non-viable, regardless of its own policy, meaning that its assets become stranded."[2422]

- December 12, 2017 – Under pressure from investors, Exxon agreed to disclose more details about climate risks by filing with the SEC, in a Form 8-K, a statement that said the company would no longer resist motions from shareholders seeking this information.[2423]

- June 16, 2017 – Because of a persistent slump in gas prices and the declining productivity of many of its Marcellus Shale wells, the revenue from gas drilling fees fell for a third straight year in Pennsylvania. The annual fee revenue goes to county and municipal governments, roadway repairs, and infrastructure upgrades, among other things.[2424]

- April 3, 2017 – A British team of researchers assessed the physical footprint of well pads in Europe and the United Kingdom if shale gas development goes forward. When they included proposed setbacks for the UK—the minimal distance well pads have to be away from existing homes and other infrastructure—they found that recoverable oil and gas would be limited by 74 percent.[2425]

- March 25, 2017 – The *Economist* took shale fracking to task for its unstable finances and inability to turn a profit. "Shale firms are on an unparalleled money-losing streak. About $11bn was torched in the last quarter, as capital expenditures exceeded cashflows. The cash-burn rate may well rise again this year. . . . The oil bulls of Houston have yet to prove that they can pump oil and create value at the same time."[2426]

- March 21, 2017 – An MIT study questioned the U.S. Energy Information Administration's rosy projections on the abundance and availability of shale gas and oil. Analyzing field data on oil wells in North Dakota's Williston Basin, the authors found that advances in fracking technology, such as the shift to longer laterals per well, have had a more modest impact on boosting oil and gas production than the agency had

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[2422] J.-F. Mercure et al., "Macroeconomic Impact of Stranded Fossil Fuel Assets," *Nature Climate Change* 8, no. 7 (2018): 588–93, https://doi.org/10.1038/s41558-018-0182-1.
[2423] David Hasemyer and John H. Cushman Jr., "Exxon Agrees to Disclose Climate Risks Under Pressure from Investors," *Inside Climate News*, December 12, 2017, https://insideclimatenews.org/news/12122017/exxon- climate-risk-disclosure-sec-shareholder-investigation-pressure.
[2424] C. Carlson, "Pennsylvania Gas Drilling Fee Revenue Falls for Third Year," *WENY News*, June 16, 2017, https://www.weny.com/story/35680098/pennsylvania-gas-drilling-fee-revenue-falls-for-third-year.
[2425] S.A. Clancy et al., "An Assessment of the Footprint and Carrying Capacity of Oil and Gas Well Sites: The Implications for Limiting Hydrocarbon Reserves," *Science of The Total Environment* 618 (2018): 586–94, https://doi.org/10.1016/j.scitotenv.2017.02.160.
[2426] "America's Shale Firms Don't Give a Frack about Financial Returns," *The Economist*, March 25, 2017, https://www.economist.com/business/2017/03/25/americas-shale-firms-dont-give-a-frack-about-financial-returns.

estimated. At the same time, the attraction of operators to the most productive areas of basins has had a greater impact. As time goes by, the prime drilling spots with the easy-to-extract oil or gas will get used up, the authors argued, and technology may not be able to compensate.[2427, 2428]

- March 2, 2017 – In 2016, Chevron became the first major oil company to warn investors in its Form 10-K, which oil and natural gas companies are required to file with the U.S. Securities and Exchange Commission, about the risk of climate change lawsuits. "Increasing attention to climate change risks has resulted in an increased possibility of governmental investigations and, potentially, private litigation against the company."[2429]

- July 7, 2016 – "Oil-field-services companies are depleted after slashing prices and laying off workers, and their slow recovery could crimp the energy industry's overall ability to bounce back from the oil bust," according to the *Wall Street Journal*. Almost 70 percent of fracking equipment in the United States has been idled, and 60 percent of field workers involved in fracking have been laid off. Halliburton alone has laid off over 28,500 workers, which is one third of its workforce. More than 70 oilfield services companies have filed for bankruptcy since the beginning of 2015.[2430]

- June 15, 2016 – Billions of dollars of proven reserves have become unproven this year, as "59 U.S. oil and gas companies deleted the equivalent of 9.2 billion barrels, more than 20 percent of their inventories," according to *Bloomberg*. In 2009, the Securities and Exchange Commission (SEC) made it easier for the companies to include in their proven reserves undeveloped acreage and wells that wouldn't be drilled for years on the grounds that "shale prospects are predictable across wide expanses." Since then, the SEC has become more strict about inflated reserves estimates.[2431]

- May 16, 2016 – *CNN Money* reported on the two latest U.S. oil and gas bankruptcies: SandRidge Energy's Chapter 11 filing was based on roughly $4 billion of debt and came the week after the biggest such bankruptcy to date—that of Linn Energy with more than $10 billion in debt. There had been at least 29 U.S. oil and gas bankruptcies in 2016 at the date of the article's publication, bringing the 2015-2016 total to at least 64. "The industry has historically been full of wildcatters and speculators. It's not surprising we're

[2427] J.B. Montgomery and F.M. O'Sullivan, "Spatial Variability of Tight Oil Well Productivity and the Impact of Technology," *Applied Energy* 195 (2017): 344–55, https://doi.org/10.1016/j.apenergy.2017.03.038.
[2428] Christa Marshall, "Studies Attack Conventional Wisdom on Natural Gas," *E&E News*, October 6, 2017, https://web.archive.org/web/20171006225015/https://www.eenews.net/stories/1060062933.
[2429] Joe Romm, "Chevron Is First Oil Major to Warn Investors of Risks from Climate Change Lawsuits," *Think Progress*, March 2, 2017, https://thinkprogress.org/chevron-admits-climate-lawsuits-threaten-profits-33937dd562fd/#.56j1qq4h3.
[2430] Alison Sider, "Revving Up Oil Fields Won't Be So Easily Done," *Wall Street Journal*, July 7, 2016, sec. Business, https://www.wsj.com/articles/revving-up-oil-fields-wont-be-so-easily-done-1467883807.
[2431] Asjylyn Loder, "Why Billions in Proven Shale Oil Reserves Suddenly Became Unproven," *Bloomberg*, June 15, 2016, https://www.bloomberg.com/news/articles/2016-06-15/shale-drillers-paper-wells-draw-sec-scrutiny-before-vanishing.

going through this boom-and-bust cycle," the article quoted the managing director at oil restructuring firm SOLIC Capital, George Koutsonicolis, as saying.[2432]

- May 9, 2016 – "The pace of oil patch bankruptcies is picking up," a *Forbes* piece read, listing the 15 biggest such bankruptcies to date. "All told, 69 oil and gas producers with $34.3 billion in cumulative secured and unsecured debt have gone under."[2433]

- March 25, 2016 – Oil and gas borrowers "feasted on what Bloomberg estimates was $237 billion of easy money without scrutinizing whether the loans could endure a drastic downturn," according to a *Washington Post* piece focusing on one company, Swift Energy, which itself was $1.349 billion in debt and had entered bankruptcy. Despite having been cautious prior to the Texas fracking boom, "[a]s the company began to frack more often, the amount it spent on exploration and drilling skyrocketed by hundreds of millions of dollars." Those expenses combined with global developments led to its failure, along with over 40 other oil and gas companies in 2015. "The consequences are far-reaching. The U.S. oil industry, having grown into a giant on par with Saudi Arabia's, is shrinking, with the biggest collapse in investment in energy in 25 years. More than 140,000 have lost energy jobs. Banks are bracing for tens of billions of dollars of defaults, and economists and lawyers predict the financial wreckage will accelerate this year."[2434]

- March 10, 2016 – Crude oil production is not falling as quickly as predicted, given the sharp decline in prices and the drop-off in new drilling and fracking operations. As reported by Reuters, this disconnect is due to refracking of older wells, along with other unconventional techniques such as "choking" and "lifting," which can extend the productive lives of wells or otherwise capture more product from them.[2435]

- March 1, 2016 – An analysis of fracking trends in the journal *Nature* concluded that a European shale gas boom was unlikely due to disappointing early yields (Poland, Lithuania and Denmark), links to earthquakes (United Kingdom), and intense public opposition in densely populated areas throughout the continent.[2436]

- June 19, 2015 – A *Bloomberg Business* analysis of the 62 drilling companies in the Bloomberg Intelligence North America Independent Exploration and Production Index found that the companies' debt continued to be a major problem. For 27 of the 62 companies, interest payments were consuming more than 10 percent of revenue. Drillers'

[2432] Matt Egan, "Oil Bankruptcies Mount despite Crude Rebound," *CNNMoney*, May 16, 2016, https://money.cnn.com/2016/05/16/investing/sandridge-energy-oil-bankruptcy/index.html.
[2433] Christopher Helman, "The 15 Biggest Oil Bankruptcies (So Far)," *Forbes*, May 9, 2016, sec. Energy, https://www.forbes.com/sites/christopherhelman/2016/05/09/the-15-biggest-oil-bankruptcies-so-far/.
[2434] Chico Harlan, "The Big Bust in the Oil Fields," *The Washington Post*, March 25, 2016, https://www.washingtonpost.com/news/wonk/wp/2016/03/25/the-big-bust-in-the-oil-fields/.
[2435] Swetha Gopinath and Amrutha Gayathri, "Forget Fracking. Choking and Lifting Are Latest Efforts to Stem U.S. Shale Bust," *Reuters*, March 9, 2016, sec. Commodities News, https://www.reuters.com/article/us-usa-shale-analysis-idUSKCN0WB1AI.
[2436] Mason Inman, "Can Fracking Power Europe?," *Nature* 531, no. 7592 (2016): 22–24, https://doi.org/10.1038/531022a.

debt rose to $235 billion at the end of the first quarter, a 16 percent increase over the year prior. *Bloomberg Business* expressed concern that shale drillers have "consistently spent money faster than they've made it, even when oil was $100 a barrel." S&P assigned speculative, or junk, ratings to 45 of the 62 companies in Bloomberg's index.[2437]

- April 7, 2015 – A Moody's Investors Service analysis of liquefied natural gas (LNG) prospects found that lower oil prices were causing suppliers to defer or cancel most proposed LNG projects. Moody's found that this was due in part to the drop in international oil prices relative to U.S. natural gas prices, thus removing the economic advantage of U.S. LNG projects. Moody's stated, "LNG is a capital-intensive infrastructure business prone to periodic construction cycles that lead to overcapacity, which we expect will continue for the rest of the decade."[2438]

- March 20, 2015 – A study by the Energy Watch Group in Germany found that the costs of allowing fracking in Germany would outweigh the benefits, noting in part that natural gas trading in the United States has been declining since 2009. The study also noted the costs of infrastructure, environmental and health risks and pointed to the need to expand renewable energy.[2439]

- December 19, 2014 – An International Energy Agency (IEA) report projected that U.S. domestic oil supplies, dominated by fracking, face challenges, and oil output from shale formations output, will level off and decline in the early 2020s.[2440] IEA Chief Economist Fatih Birol said, "A well-supplied oil market in the short-term should not disguise the challenges that lie ahead."[2441]

- August 29, 2014 – Andrew Nikiforuk, a Canadian energy analyst, reported on diminishing returns and the higher-cost, higher-risk nature of fossil fuel extraction by fracking. Nikiforuk wrote, "Most of the world's oil and gas firms are now pursuing extreme hydrocarbons because the cheap and easy stuff is gone…. That means industry will spend more good money chasing poor quality resources. They will inefficiently mine and frack ever larger land bases at higher environmental costs for lower energy returns."[2442]

[2437] Asjylyn Loder, "The Shale Industry Could Be Swallowed By Its Own Debt," *Bloomberg*, June 18, 2015, https://www.bloomberg.com/news/articles/2015-06-18/next-threat-to-u-s-shale-rising-interest-payments.
[2438] Moody's Investors Service, "Lower Oil Prices Cause Suppliers of Liquefied Natural Gas to Nix Projects," *Moodys.Com*, April 7, 2015, sec. Ratings & Assessments News, http://www.moodys.com:18000/research/Moodys-Liquefied-natural-gas-projects-nixed-amid-lower-oil-prices--PR_322439.
[2439] Nicole Sagener, "Fracking Costs Outweigh Benefits for Germany and Europe, Study Says," *EurActiv*, March 20, 2015, sec. Energy, https://www.euractiv.com/section/energy/news/fracking-costs-outweigh-benefits-for-germany-and-europe-study-says/.
[2440] International Energy Agency, "World Energy Outlook 2014 – Executive Summary," December 2014, https://iea.blob.core.windows.net/assets/e6f58562-203e-474c-97a3-486f409aa7ff/WEO2014.pdf.
[2441] Dennis Dimick, "How Long Can the U.S. Oil Boom Last?," *National Geographic*, December 19, 2014, sec. Science, https://www.nationalgeographic.com/science/article/141219-fracking-oil-supply-price-reserves-profits-environment.
[2442] Andrew Nikiforuk, "A Big Summer Story You Missed: Soaring Oil Debt," *The Tyee*, August 29, 2014, http://thetyee.ca/Opinion/2014/08/29/Soaring-Oil-Debt-Summer/.

- July 29, 2014 – According to the U.S. Energy Information Administration, energy companies are incurring increasing debt and selling assets to continue drilling in shale. "Based on data compiled from quarterly reports, for the year ending March 31, 2014, cash from operations for 127 major oil and natural gas companies totaled $568 billion, and major uses of cash totaled $677 billion, a difference of almost $110 billion. This shortfall was filled through a $106 billion net increase in debt and $73 billion from sales of assets . . ."[2443]

- July 2014 – Researchers at the Washington, DC-based Environmental Law Institute and Washington & Jefferson College in Pennsylvania collaborated to produce a report designed in part to help communities avoid the "boom and bust" cycles of extractive industries. Authors warned, "While resource extraction has long been regarded as an economic benefit, a body of academic literature suggests that long term growth based chiefly on resource extraction is rare." Confounding factors include transience of the workforce, localized inflation, widening disparities in royalties and impact fee disbursement, commodity price volatility, and communities overspending on infrastructure.[2444]

- June 19, 2014 – Energy analyst Deborah Lawrence Rogers outlined the spiraling debt and severe deterioration of the assets of five major shale gas drillers over the last five years. She concluded, "This is not sustainable. It could be argued that it is not even moral. It is a failed business model of epic proportion. While companies could make the argument at one time that this was a short term downtrend, that no longer holds water because this pattern is long term."[2445]

- April 10, 2014 – A report by a petroleum geologist and petroleum engineer concluded the 100-year supply of shale gas is a myth, distinguished between what is technically recoverable and economically recoverable shale gas, and asserted that at current prices, New York State has no economically recoverable shale gas.[2446]

- February 28, 2014 – Maria van der Hoeven, Executive Director of the IEA, said in an interview with *The Christian Science Monitor* that there is only a decade left in the U.S.

[2443] U.S. Energy Information Administration, "As Cash Flow Flattens, Major Energy Companies Increase Debt, Sell Assets," *Today in Energy*, July 29, 2014, https://www.eia.gov/todayinenergy/detail.php?id=17311.
[2444] Environmental Law Institute & Washington & Jefferson College, "Getting the Boom without the Bust: Guiding Southwestern Pennsylvania through Shale Gas Development," 2014, https://www.eli.org/sites/default/files/eli-pubs/getting-boom-final-paper-exec-summary-2014-07-28.pdf.
[2445] Deborah Lawrence Rogers, "Huge CAPEX = Free Cash Flow? Not in Shales," *Energy Policy Forum*, June 19, 2014, https://web.archive.org/web/20130630100230/http://energypolicyforum.org/2013/06/19/huge-capex-free-cash-flow-not-in-shales/.
[2446] Labyrinth Consulting Services, Inc., A. Berman, and L. Pittinger, "Resource Assessment of Potentially Producible Natural Gas Volumes From the Marcellus Shale, State of New York," https://www.slideshare.net/MarcellusDN/resource-assessment-of-potentially-producible-natural-gas-volumes-from-the-marcellus-shale-state-of-new-york.

shale oil and gas boom, noting that her agency's analysis predicts that production will soon flatten out and, by 2025, begin to decline.[2447]

- December 18, 2013 – A University of Texas study in *Proceedings of the National Academy of Sciences* found that fracking well production drops sharply with time, which undercuts the oil and gas industry's economic projections.[2448] In an interview about the study with *StateImpact NPR* in Texas, Tad Patzek, Chair of the Department of Petroleum and Geosystems Engineering at University of Texas at Austin, noted that fracking "also interferes now more and more with daily lives of people. Drilling is coming to your neighborhood, and most people abhor the thought of having somebody drilling a well in their neighborhood."[2449]

- August 18, 2013 – *Bloomberg News* reported that low gas prices and disappointing wells have led major companies to devalue oil and gas shale assets by billions of dollars.[2450]

- October 21, 2012 – The *New York Times* reported that many gas drilling companies overproduced natural gas backed by creative financing and now "are committed to spending far more to produce gas than they can earn selling it." "We are all losing our shirts today," said Exxon CEO Rex Tillerson in the summer of 2012.[2451]

- July 13, 2012 – *The Wall Street Journal* reported that ITG Investment Research, at the request of institutional investors, evaluated the reserves of Chesapeake Energy Corporation's shale gas reserves in the Barnett and Haynesville formations and found them to be only 70 percent of estimates by Chesapeake's engineering consultant for the company's 2011 annual report. Chesapeake and its consultant defended their figures.[2452]

- August 23, 2011 – The U.S. Geological Survey (USGS) cut the government's estimates of natural gas in the Marcellus Shale from 410 trillion cubic feet to 84 trillion cubic feet, equivalent to a reduction from approximately 16 years of U.S. consumption at current levels of natural gas use, to approximately 3.3 years of consumption. The USGS's

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[2447] D. J. Unger, "IEA Chief: Only a Decade Left in US Shale Oil Boom," *Christian Science Monitor*, February 28, 2014, https://www.csmonitor.com/Environment/Energy-Voices/2014/0228/IEA-chief-Only-a-decade-left-in-US-shale-oil-boom.
[2448] Tad W. Patzek, Frank Male, and Michael P. Marder, "Gas Production in the Barnett Shale Obeys a Simple Scaling Theory," *Proceedings of the National Academy of Sciences* 110, no. 49 (2013): 19731–36, https://doi.org/10.1073/pnas.1313380110.
[2449] Mose Buchele, "New Study Shows How Gas Production From 'Fracked' Wells Slows Over Time," *State Impact Texas*, December 18, 2013, https://stateimpact.npr.org/texas/2013/12/18/new-study-shows-how-gas-production-from-fracked-wells-slows-over-time/.
[2450] Matthew Monks, Rebecca Penty, and Gerrit de Vynck, "Shale Grab in U.S. Stalls as Falling Values Repel Buyers: Energy," *Bloomberg*, August 18, 2013, https://www.bloomberg.com/news/articles/2013-08-18/shale-grab-in-u-s-stalls-as-falling-values-repel-buyers.
[2451] Clifford Krauss and Eric Lipton, "After the Boom in Natural Gas," *The New York Times*, October 20, 2012, https://www.nytimes.com/2012/10/21/business/energy-environment/in-a-natural-gas-glut-big-winners-and-losers.html?pagewanted=all.
[2452] Matt Wirz, "Chesapeake Reserve Doubted," *Wall Street Journal*, July 13, 2012, sec. Business, https://online.wsj.com/article/SB10001424052702303644004577523411723501548.html.

updated estimate was for natural gas that is technically recoverable, irrespective of economic considerations such as the price of natural gas or the cost of extracting it.[2453]

- June 26-27, 2011 – As reported in two *New York Times* stories, hundreds of emails, internal documents, and analyses of data from thousands of wells from drilling industry employees, combined with documents from federal energy officials, raised concerns that shale gas companies were overstating the amount of gas in their reserves and the profitability of their operations.[2454, 2455, 2456] The *New York Times*' public editor criticized the stories, but offered no evidence that the major findings were wrong.[2457] The *New York Times*' news editors publicly defended both stories against the public editor's criticism.[2458, 2459]

[2453] U.S. Geological Survey, "USGS Releases New Assessment of Gas Resources in the Marcellus Shale, Appalachian Basin," August 23, 2011, https://www.usgs.gov/science-explorer-results?es=USGS+releases+new+assessment+of+gas+resources+in+the+Marcellus+shale%2C+Appalachian+Basin.
[2454] Ian Urbina, "Insiders Sound an Alarm Amid a Natural Gas Rush," *The New York Times*, June 26, 2011, sec. U.S., https://www.nytimes.com/2011/06/26/us/26gas.html.
[2455] U.S. Energy Information Administration, "U.S. Natural Gas Summary," May 30, 2014, https://www.eia.gov/dnav/ng/ng_sum_lsum_dcu_nus_a.htm.
[2456] Ian Urbina, "Geologists Sharply Cut Estimate of Shale Gas," *The New York Times*, August 25, 2011, sec. U.S., https://www.nytimes.com/2011/08/25/us/25gas.html.
[2457] Arthur S. Brisbane, "Opinion | Clashing Views on the Future of Natural Gas," *The New York Times*, July 16, 2011, sec. Opinion, https://www.nytimes.com/2011/07/17/opinion/sunday/17pubed.html.
[2458] Arthur S. Brisbane, "Times Editors Respond to My Shale Gas Column," *The New York Times*, July 17, 2011, sec. Opinion, https://publiceditor.blogs.nytimes.com/2011/07/17/times-editors-respond-to-my-shale-gas-column/.
[2459] Arthur S. Brisbane, "Times Editors Respond to Column on Redactions," *The New York Times*, July 30, 2011, http://publiceditor.blogs.nytimes.com/2011/07/30/times-editors-respond-to-column-on-redactions/.

Medical and scientific calls for more study, reviews confirming evidence of harm, and calls for increased transparency and science-based policy

As published reviews and international governmental reports underscore the mounting evidence of health risks—including developmental, neurological, carcinogenic, respiratory, reproductive, and psychological—medical professionals and scientists in the United States and around the world increasingly call for the suspension of fracking in order to prevent its adverse public health harms, including health threats from climate change. Organizations of medical professionals and scientists are also issuing calls for comprehensive, long-term study of the full range of potential health and ecosystem effects of fracking. These appeals underscore the accumulating evidence of harm, point to the knowledge gaps that remain, and decry the atmosphere of secrecy and intimidation that continues to impede the progress of scientific inquiry.

- June 6, 2023 – Forty-five medical professionals who work or have previously worked as pediatricians in the Northern Territory, Australia signed a letter calling on their government to re-evaluate the health costs of moving forward with fracking in the Beetaloo Basin, and to "embrace urgent climate action." According to one signer, "For these doctors to be doing this really, I think, reflects the extent of their concern and their worry about their patient populations." The letter references the direct health risks identified in the United States, noting that millions of people there live within two kilometers of a fracked oil or gas well.[2460]

- December 23, 2022 – On the occasion of releasing its newest report, "Communities in Flux. Fracking and Health Impacts: The Lived Experience," Canadian Association of Physicians for the Environment (CAPE), restated its call for a moratorium on fracking in British Columbia. Based on a survey of 53 people living within five kilometers of fracking sites in the province's Peace region, their report provides new data on the health symptoms, diagnoses, and adverse physical conditions (such as odors and noise) experienced by respondents. CAPE's nine recommendations include ending government subsidies for fracking and more action to protect community members and workers. "Community health studies, notably co-designed with Indigenous residents, should be undertaken to document any adverse health impacts, and plans for the treatment and prevention of illnesses should be developed. In particular, the impacts on oil and gas workers' physical and mental health in Northeastern B.C. is a significant gap in literature and understanding that should be addressed."[2461, 2462]

[2460] Samantha Dick, "Paediatricians Sign Joint Letter Urging NT Government to Withdraw Beetaloo Basin Fracking Support," *ABC News*, June 6, 2023, https://www.abc.net.au/news/2023-06-07/nt-paediatrians-sign-letter-warning-fracking-health-risks/102440510.
[2461] Stefan Labbé, "'People from the Sacrifice Zone': Doctors Call for Moratorium on B.C. Fracking," *BIV*, December 23, 2022, https://biv.com/article/2022/12/people-sacrifice-zone-doctors-call-moratorium-bc-fracking.
[2462] Canadian Association of Physicians for the Environment (CAPE), "Communities in Flux. Fracking and Health Impacts: The Lived Experience," May 2022, https://cape.ca/wp-content/uploads/2022/12/Communities-in-Flux-%E2%80%93-Fracking-and-Health-Impacts.pdf.

- July 12, 2022 – A new report and fact sheet from Physicians for Social Responsibility (PSR) examine chemical disclosure standards related to fracking in 16 states. PSR's five resulting public health-related demands include detailed disclosure laws and practices to address the significant existing gaps that are currently preventing "full identification of these chemicals and their associated health and environmental risks."[2463]

- February 15, 2022 – In an open letter to the UK prime minister, United Kingdom medical institutions, with a combined membership of more than 250,000 health care professionals, called for an immediate halt to new oil and gas exploration and an end to the country's dependency on fossil fuels. "As healthcare professionals, we know that any new fossil fuel projects and their contribution to climate change constitute a grave threat to our patients and the resilience of our healthcare system."[2464]

- June 26, 2021 – The president and CEO of Mental Health Colorado called for a systemic shift away from the "harmful and short-sighted cycle of boom and bust" energy policies, noting that the oil and gas industry's activities in the state have led to chronic stress, depression, and anxiety among Colorado residents. Impacts threatening mental health include light pollution, noise pollution, safety concerns, landscape changes, and feelings of powerless in local decision-making. "Coloradans who have called these communities home for generations find that they often have little to say about the transformation of their world by an invasion of powerful industry." The author also urged "true representation in the decision-making process."[2465]

- June 8, 2021 – A sweeping review of the research on the environmental, economic, and anthropogenic impacts of fracking called for greater focus on the inevitable bust periods that follow fracking booms, noting that most research findings have been solely based on investigations of boom-time activities. In their analysis on costs and benefits of fracking, this team of economists and public health scientists examined the literature on local air pollution, global air pollution, water pollution, noise, light, seismic activity, direct and indirect measures of health, migration, education, labor, income, agriculture, and environmental justice. Their analysis showed mixed results and revealed data gaps. The authors emphasized that an understanding of all these impacts is critical for policy makers, who now must also pay attention to changes affecting communities while the industry contracts due to factors such as the COVID pandemic.[2466]

- June 4, 2021 – Following the fourth "near-miss" in nine months at the Enbridge North Weymouth gas compressor (a release of over 11,000 cubic feet of highly pressurized gas,

[2463] Dusty Horwitt and Meilen Teklemichael, "Chemical Makers' Exemptions from Fracking Chemical Disclosure Rules" (Physicians for Social Responsibility, July 12, 2022), https://psr.org/new-from-psr-gaps-in-fracking-chemical-disclosure-rules-may-pose-threat-to-human-health/.
[2464] Adele Waters, "Medical Leaders Urge Ministers to End UK's Fossil Fuel Dependence," *BMJ*, 2022, o389, https://doi.org/10.1136/bmj.o389.
[2465] Vincent Atchity, "Opinion: Another Factor to Keep in Mind in Colorado's Oil and Gas Communities — Healthy Minds," *The Colorado Sun*, June 26, 2021, https://coloradosun.com/2021/06/26/mental-health-oil-gas-opinion/.
[2466] Katie Jo Black et al., "Economic, Environmental, and Health Impacts of the Fracking Boom," *Annual Review of Resource Economics* 13 (2021), https://doi.org/10.1146/annurev-resource-110320-092648.

following large leaks on September 11, September 30, and April 6), two prominent Boston-area physician-researchers appealed for the facility to be shut down. Dr. Caren Solomon, a deputy editor at the *New England Journal of Medicine,* an associate professor of medicine at Harvard Medical School, and a physician at the Brigham and Women's Hospital, and Dr. Philip J. Landrigan, Professor at Boston College (BC) and Director of BC's Program for Global Public Health and the Common Good, wrote, "Enbridge's cavalier reaction is typical of the arrogance, dishonesty, lack of regulatory oversight, and lack of concern for public safety that has characterized the North Weymouth compressor project from its beginning." They welcomed the retraction of the state's own flawed Health Impact Assessment but noted that state support of the project should have been withdrawn much sooner.[2467]

- May 17, 2021 – Fracking was named as an emerging concern by the American Pediatric Society in its statement on ambient air pollution harming children. The authors of "Policy Statement on Organizational Principles to Guide and Define the Child Health Care System and/or Improve the Health of all Children" identified fracking wells, flare stacks, water storage pits, tanks, sand operations, and diesel-powered equipment and trucks as contributors of multiple air pollutants, including toxic vapors, and criteria air pollutants, such as nitrogen oxides and fine particles. They also noted that fracking pollutants are among those named that originate outdoors but that may enter buildings and vehicles through open doors and windows, ventilation systems, and cracks in structures. By these pathways, fracking can exacerbate the burden of indoor-derived air pollutants on children.[2468]

- April 26, 2021 – Three faculty members at the Columbia University Mailman School of Public Health called for a rapid phaseout of fracking. Noting exemptions from "an astonishing list" of key federal regulations, the authors outlined the many significant risks research has documented for pregnant people, including congenital heart defects, elevated maternal stress from noise and light pollution, and endocrine disruption. They also noted environmental injustices from disproportionate impacts on low-income communities. "For the millions of Americans directly affected by fracking, it's time to put their health, and the health of future generations health, first and stop these injustices."[2469]

- January 25, 2021 – Dr. Philip J. Landrigan, a leading pediatrician, epidemiologist, and public health physician, wrote to the Federal Energy Regulatory Commission to request reexamination of the agency's decision to permit the operation of a natural gas compressor station in North Weymouth, Massachusetts. Dr. Landrigan critiqued the limited scope of the state's Health Impact Assessment, citing deficiencies in its review of

[2467] Caren Solomon and Philip Landrigan, "Enough Is Enough. It's Time To Shut Down The Weymouth Compressor," WBUR, June 4, 2021, https://www.wbur.org/cognoscenti/2021/06/04/weymouth-compressor-leak-shutdown-caren-solomon-philip-landrigan.
[2468] Heather L. Brumberg and Catherine J. Karr, "Ambient Air Pollution: Health Hazards to Children," *Pediatrics* 147, no. 6 (2021), https://doi.org/10.1542/peds.2021-051484.
[2469] Chelsea Clinton, Terry McGovern, and Micaela Martinez, "End Fracking Exemptions, a Threat to Maternal and Public Health," *Stat*, April 26, 2021, https://www.statnews.com/2021/04/26/end-fracking-exemptions-a-threat-to-maternal-and-public-health/.

fire and explosion hazards, toxic emissions, existing chronic disease burden in the community, economic and racial justice concerns, and climate impacts.[2470]

- June 1, 2020 – Writing in the *Lancet*, biologist and endocrinologist Barbara A. Demeneix called for recognition of, and action on, the interlinked threats to life brought by fossil fuels, specifically highlighting fracking. She described a web of threats originating with fossil fuel extraction and highlighted the dangers of endocrine-disrupting chemicals, writing that, "Gas derived from fracking is rapidly driving the development of new petrochemical and plastics plants worldwide," and those stark increases harm health, biodiversity, and the climate. Urgent attention, political support, and investment in alternative energies will reduce these harms and help attain the United Nations sustainable development goals.[2471]

- May 9, 2020 – The Advisory Committee of the German Society of Toxicology, the largest scientific toxicological organization in Europe, published a "Critical evaluation of human health risks due to hydraulic fracturing in natural gas and petroleum production."[2472] Among their conclusions: strong evidence links fracking fluids to local environmental contamination; fracking fluids that contain known human carcinogens cannot be confirmed as safe; and the health risks from fracking can include long-lasting contamination of soil and water. Reviewers noted that the "… most critical part of risk assessment in this context is the exposure assessment which is hampered by the unavailability of data from qualified baseline monitoring" before the start of fracking operations.

- February 24, 2020 – An open letter signed by over 50 health care professionals cited health risks related to fracking and climate change in their expressed opposition to the continued construction of the Coastal GasLink fracked gas pipeline in in northern British Columbia.[2473] They wrote, "the health risks from fracking are well known, including release of carcinogenic toxins such as benzene. Pregnant women in northeastern B.C. have serum benzene levels three times the normal level and studies have shown this has an association with increased childhood leukemia rates. U.S. studies have shown increases in congenital heart disease, chronic pulmonary disorders and small birth-weight babies in populations living in proximity to fracking operations. And as we all know, every pipeline leaks." Their letter expressed solidarity with Indigenous rights of Wet'suwet'en, whose land is being annexed for this pipeline without their consent.

[2470] Philip J. Landrigan, "Re: Natural Gas Compressor Station in North Weymouth, Massachusetts," Letter to the Federal Energy Regulatory Commission, January 25, 2021.
[2471] Barbara A Demeneix, "How Fossil Fuel-Derived Pesticides and Plastics Harm Health, Biodiversity, and the Climate," *The Lancet Diabetes & Endocrinology* 8, no. 6 (2020): 462–64, https://doi.org/10.1016/S2213-8587(20)30116-9.
[2472] Klaus-Michael Wollin et al., "Critical Evaluation of Human Health Risks Due to Hydraulic Fracturing in Natural Gas and Petroleum Production," *Archives of Toxicology* 94, no. 4 (2020): 967–1016, https://doi.org/10.1007/s00204-020-02758-7.
[2473] Various Authors, "Health Professionals Call for a Moratorium on Coastal GasLink Construction Permits," *Ricochet*, February 24, 2020, https://ricochet.media/en/2952.

- January 29, 2020 – A new report outlining the serious health and environmental dangers of fracking by Canadian Association of Physicians for the Environment called for a moratorium on the development of new fracked natural gas wells in each province and territory across Canada; plans to phase out existing fracking wells to meet Canada's commitments under the Paris Agreement; Health and Equity Impact Assessments to prioritize wells for early closure; and "Just Transition" plans to help workers and their 14communities prepare for the new low-carbon economy.[2474] In a press release, Dr. Éric Notebaert, member of the Association and advisor to the report, outlined findings of urgent concern and strong evidence including low birth weight, "an indicator for a number of serious health impacts including developmental deficits in children and increased rates of cardiovascular disease in later life."[2475]

- January 9, 2020 – "Gas is associated with health and environmental hazards and reduced social welfare at every stage of its life cycle," wrote three medical doctors in the *New England Journal of Medicine.*[2476] The piece briefly highlighted those hazards from the well to transport and storage, from routine exposures to explosions, as well as providing an up-to-date summary of the threat to the climate by continued extraction and use of fracked gas. The authors stated, "As physicians deeply concerned about climate change and pollution and their consequences, we consider expansion of the natural-gas infrastructure to be a grave hazard to human health," calling for "courageous political leadership" to enact the appropriate policies.

- January 8, 2020 – An interdisciplinary team headed by Yale environmental health epidemiologist Nicole Deziel together with Israeli colleagues conducted a scoping review to assess what is known about the human health outcomes associated with fracking. Of the 29 studies that met their criteria for inclusion, 25 reported at least one statistically significant adverse health outcome linked to a fracking-related exposure. The authors concluded that a growing body of evidence shows health problems in communities near drilling and fracking sites. They also emphasized that many health outcomes may take years to emerge, partly because of latency periods for diseases such as cancer. They stated that while it is important that these data be replicated in other populations, "the need for more research need not be used as a barrier to implementing policies."[2477]

- November 19, 2019 – A letter signed by over 100 leading Israeli scientists, including Nobel laureate Robert Aumann, called for the reversal of the government's decision to

[2474] Ronald Macfarlane and Kim Perrotta, "Fractures in the Bridge: Unconventional (Fracked) Gas, Climate Change and Human Health" (Canadian Association of Physicians for the Environment, 2020), https://cape.ca/wp-content/uploads/2020/01/CAPE-Fracking-Report-EN.pdf.
[2475] Milissa Hughes, "Doctors Release New Report Calling for Moratorium on Fracking in Canada" (Canadian Association of Physicians for the Environment, January 29, 2020), https://cape.ca/wp-content/uploads/2020/01/Fracking-press-release-EN-Jan-29.pdf.
[2476] Philip J. Landrigan, Howard Frumkin, and Brita E. Lundberg, "The False Promise of Natural Gas," *New England Journal of Medicine* 382, no. 2 (2020): 104–7, https://doi.org/10.1056/NEJMp1913663.
[2477] Nicole C. Deziel et al., "Unconventional Oil and Gas Development and Health Outcomes: A Scoping Review of the Epidemiological Research," *Environmental Research* 182 (2020): 109124, https://doi.org/10.1016/j.envres.2020.109124.

build a new network of 16 gas-fired power plants.[2478] In their appeal to transition to renewable energy rather than to gas, they cite the powerful short-term climate warming impact of methane as well as carcinogenic emissions. "During the production, refining and delivery of the gas, much greater quantities of methane are released than were previously recognized. These emissions contain volatile organic compounds that are recognized as carcinogenic." The letter also warned of negative economic and social impacts of building out a gas infrastructure instead of investing in renewables.

- November 19, 2019 – Brian Schwartz, a professor of environmental health and engineering at Johns Hopkins Bloomberg School of Public Health, called for a ban on fracking while addressing a public health conference in Pittsburgh.[2479] "Schwartz, who has presented his research at the conference in the past, but had never before called for a ban on fracking, said he'd recently become convinced the time had come to make a public statement." Dr. Schwartz cited years of studies indicating that proximity to fracking increases the risk of asthma, premature birth, headaches, and maternal stress levels, concluding that "the evidence that fracking is bad for your health is clear enough."

- June 15, 2019 – A Colorado and Pennsylvania team of epidemiologists summarized the literature to date on the health effects of populations living near fracking operations, with a focus on methodological rigor. They adapted systematic review frameworks from the medical and environmental health field, analyzing 20 epidemiologic studies, with 32 different health outcomes, ranging from self-reported symptoms to confirmed disease diagnoses. The review's highest rated studies primarily focused on birth outcomes, and in general they found that study quality has improved over time. They found that studies of populations living near fracking operations provide "modest scientific findings" of "harmful health effects including asthma exacerbations and various self-reported symptoms."[2480] The review includes an important discussion of the limitations inherent to observational epidemiologic studies and the necessity of combining them with exposure and risk assessments to inform public health and policies. Differences in observational epidemiologic study types make comparing results across studies a difficult task. The authors recommend researchers "integrate community members and concepts of health equity and environmental justice into their research approaches."

- March 29, 2019 – Doctors for the Environment Australia announced the reinforcement of its position that no new gas extraction of any kind should occur in Australia. Its position was largely informed by the wealth of literature from the United States documenting

[2478] Sue Surkes, "112 Top Scientists Call on Government to Abort Plan for Gas-Fired Power Stations," *The Times of Israel*, November 19, 2019, https://www.timesofisrael.com/leading-scientists-call-on-government-to-abort-plan-for-gas-fired-power-stations/.
[2479] Reid Frazier, "Johns Hopkins Researcher: Pa. Should Ban Fracking," *State Impact Pennsylvania*, November 20, 2019, https://stateimpact.npr.org/pennsylvania/2019/11/20/johns-hopkins-researcher-pa-should-ban-fracking/.
[2480] Alison M. Bamber et al., "A Systematic Review of the Epidemiologic Literature Assessing Health Outcomes in Populations Living near Oil and Natural Gas Operations: Study Quality and Future Recommendations," *International Journal of Environmental Research and Public Health* 16, no. 12 (2019): 2123, https://doi.org/10.3390/ijerph16122123.

adverse health findings.[2481] The organization's review found growing evidence of direct health impacts as well as a clear potential for indirect impacts of gas and oil mining on essential environmental determinants of health. "These concerns include risks to a stable climate, air quality, water quality, water security, food security, community cohesion and, in some locations, geological stability. The cumulative impacts of these industries on the wider requirements for good health and wellbeing are extremely concerning."[2482]

- February 1, 2019 – Natural gas extraction via fracking is associated with "preterm birth, high-risk pregnancy, and possibly low birth weight; three types of asthma exacerbations; and nasal and sinus, migraine headache, fatigue, dermatologic, and other symptoms," according to a review covering research through mid-2017.[2483] The Johns Hopkins Bloomberg School of Public Health scientists cited the methodological robustness of these studies and the biological plausibility of the links found. Further, they included in their review the contribution of fracking to climate change and its further health impacts. Authors expressed serious doubt that the risks of fracking can be managed. "Some have suggested that regulations will prevent health impacts, but no health studies provide guidance on what regulations, if any, will get the health effects to go away." The authors further noted that the fracking boom has, in many regions, outpaced the ability of science to document health impacts with long latencies, such as cancer and neurodegenerative diseases. The review concluded that the results of early health studies "should give pause" about whether and how shale gas fracking should proceed and referenced the several U.S. states and nations that have disallowed fracking, citing health concerns.

- December 12, 2018 – "The healthcare community has a professional mandate to protect society from harm to human health. We have a responsibility to help society move away from fossil fuels and accelerate the transition to renewable energy," wrote a team of medical professionals in an editorial for the *British Medical Journal*. Citing the "overwhelming" evidence that fossil fuels pose serious threats to public and planetary health, the group identified divestment from fossil fuel corporations as a strategy that increasing numbers of medical professional groups are taking, as part of fulfilling that professional mandate.[2484]

- December 4, 2018 – In a review of 63 studies in 20 countries, a University of Southern California medical research team concluded that the potential public health effects of "upstream oil extraction" include cancer, liver damage, immunodeficiency, and neurological damage. Collectively, onshore operations that bring crude oil to the surface

[2481] Melissa Haswell and David Shearman, "Expanding Gas Mining Threatens Our Climate, Water and Health," *The Conversation*, March 29, 2019, http://theconversation.com/expanding-gas-mining-threatens-our-climate-water-and-health-113047.
[2482] Melissa Haswell and David Shearman, "The Implications for Human Health and Wellbeing of Expanding Gas Mining in Australia: Onshore Oil and Gas Policy," Background Report (Doctors for the Environment Australia, 2019), https://apo.org.au/sites/default/files/resource-files/2019-03/apo-nid208281.pdf.
[2483] Irena Gorski and Brian S. Schwartz, "Environmental Health Concerns From Unconventional Natural Gas Development," in *Oxford Research Encyclopedia of Global Public Health*, by Irena Gorski and Brian S. Schwartz (Oxford University Press, 2019), https://doi.org/10.1093/acrefore/9780190632366.013.44.
[2484] Adam Law et al., "Medical Organisations Must Divest from Fossil Fuels," *BMJ*, 2018, k5163, https://doi.org/10.1136/bmj.k5163.

affect nearly six million people that live or work nearby. Community health, worker health, and animal health in oil-drilling regions were addressed in this review, as well as effects on soil, air, surface water, and drinking water quality. In their analysis, the authors included both conventional or unconventional extraction techniques but noted that, in the United States, hydraulic fracturing accounted for 50 percent of total oil production in 2015—up from less than two percent in 2000.[2485]

- August 16, 2018 – The closer one lives to fracking sites, the more likely one is to experience toxic exposures and a related number of health impacts. Setbacks less than one quarter mile (1,320 feet) from drilling and fracking operations are not sufficient to protect public health, and additional setbacks are needed to protect vulnerable groups and settings, according to an expert panel assembled in Pennsylvania. "Vulnerable groups were defined by the panelists as children, neonates, fetuses, embryos, pregnant women, elderly individuals, those with pre-existing medical or psychological conditions, and those with pre-existing respiratory conditions. Vulnerable settings were defined as schools, day care centers, hospitals, and long-term care facilities. The panel, which consisted of 18 health care providers, public health practitioners, environmental advocates, and researchers/scientists, was brought together to compare existing minimum setback requirements against research about the health impacts of living near fracking activity. The panel was unable to come to agreement on a minimum safe setback distance between one quarter and two miles. It also noted that the failure to achieve consensus on this issue reflects uncertainties based on limited data of real-time toxic emissions from drilling and fracking operations, the limited number of scientific studies available, and the potential for episodically recurrent periods of high exposures.[2486]

- June 5, 2018 – The exacerbation of climate change caused by shale gas development is sufficient grounds to confirm that "the risks clearly and considerably outweigh any possible benefits," according to two public health scholars who published their editorial in the *British Medical Journal*.[2487]

- May 9, 2018 – With the objective of making practical recommendations for primary care providers, researchers sought to identify all published peer-reviewed studies examining evidence of direct relationships between high-volume hydraulic fracturing and human health harms. As a scoping review, the study purpose was to examine the extent and breadth of research and identify research gaps. Their criteria for inclusion were "narrow" and included peer-reviewed journal articles from the United States, in English, published between 2000 and September 2017. Among the 18 studies selected, 10 showed a positive correlation to the negative health outcome, six showed a mixed relationship, and two found no relationship. The authors wrote, "The health impacts found in the limited

[2485] Jill E. Johnston, Esther Lim, and Hannah Roh, "Impact of Upstream Oil Extraction and Environmental Public Health: A Review of the Evidence," *Science of The Total Environment* 657 (2019): 187–99, https://doi.org/10.1016/j.scitotenv.2018.11.483.
[2486] Celia Lewis, Lydia H. Greiner, and David R. Brown, "Setback Distances for Unconventional Oil and Gas Development: Delphi Study Results," ed. Carla A. Ng, *PLOS ONE* 13, no. 8 (2018): e0202462, https://doi.org/10.1371/journal.pone.0202462.
[2487] David McCoy and Patrick Saunders, "Fracking and Health," *BMJ*, 2018, k2397, https://doi.org/10.1136/bmj.k2397.

studies in this scoping review should encourage health care providers to maintain a high index of suspicion with patients who live or have lived near [drilling and fracking] activity or who have worked in oil and gas fields."[2488]

- April 4, 2018 – Two scholars critiqued the wide-ranging consultation on unconventional gas extraction, including fracking, which was commissioned by the Scottish government and published in November 2016.[2489] Noting that the Scottish assessment is more comprehensive than assessments conducted in the United States and elsewhere, the authors wrote, "The public health impact assessment in particular is underpinned by what appears to be a rigorous and transparent examination of existing scientific literature drawing on external peer review at some stages." However, they also went on to say that some of the conclusions drawn "appear to be optimistic readings of data and experience. For example, assessments of the ability of industry and regulators to control fracking effects on public health do not stand up to scrutiny." They identified several other ways in which the health impact assessment's conclusions were not always supported by the evidence it reviewed and if the assessment had overlooked areas of concern. For example, the literature on social impact assessments, as well as health research addressing questions of well-being and mental health, were neglected. Nevertheless, these scholars recommended the Scottish consultation as a research and policy tool.

- February 12, 2018 – The Los Angeles County Department of Public Health reviewed the public health and safety risks of oil and gas facilities and identified "next steps." These included an increase in setback distances, continuous air monitoring systems around oil and gas operations, increased local oversight, a comprehensive Community Safety Plan, and Emergency Preparedness Plans. For this report, authors reviewed epidemiological literature, environmental and health impact assessments, neighborhood health investigations, and consultations with various jurisdictions regarding oil and gas ordinances.[2490] At the time of the report preparation, there were 3,468 active and 1,850 inactive oil and gas wells countywide. Conditions varied widely. Among the most egregious was an active well that was located 60 feet from a multi-unit housing complex and that shared borders with a local high school and a college dormitory. "The potential public health impacts of oil and gas sites located in densely populated areas are concerning, particularly to those who experience disproportionate economic and health inequities." Recommendations for some individual neighborhoods included offering temporary relocation assistance. "The report was ordered by the city of Los Angeles after complaints of headaches, eye and throat irritation, nausea and vomiting were received

[2488] Rosemary Wright and Richard D. Muma, "High-Volume Hydraulic Fracturing and Human Health Outcomes: A Scoping Review," *Journal of Occupational & Environmental Medicine* 60, no. 5 (2018): 424–29, https://doi.org/10.1097/JOM.0000000000001278.
[2489] Andrew Watterson and William Dinan, "Public Health and Unconventional Oil and Gas Extraction Including Fracking: Global Lessons from a Scottish Government Review," *International Journal of Environmental Research and Public Health* 15, no. 4 (2018): 675, https://doi.org/10.3390/ijerph15040675.
[2490] Katherine Butler et al., "Public Health and Safety Risks of Oil and Gas Facilities in Los Angeles County" (Los Angeles County Department of Public Health, 2018), http://publichealth.lacounty.gov/eh/docs/PH_OilGasFacilitiesPHSafetyRisks.pdf.

from residents of South Los Angeles, Wilmington and unincorporated county areas in the past several years."[2491]

- December 12, 2017 – Commissioned by the Australian government, the Scientific Inquiry into Hydraulic Fracturing in the Northern Territory released its Draft Final Report. Tasked with identifying and assessing the risks of shale gas fracking for Australia's remote Northern Territory—and with making recommendations to mitigate those risks where possible—the Inquiry describes a multiplicity of risks, including many that are ill-defined and understudied.[2492] Most notably, it recommends a halt on all fracking production licenses until a two-to-three-year study can be launched to further understand the nature of the risks for the particular ecology and culture of the region."[2493] Fracking is currently prohibited in the Northern Territory, which is estimated to hold over one-third of Australia's shale gas.

- November 7, 2017 – In a commentary published in *JAMA*, two South Dakota physicians reviewed the data on the potential public health implications of fracking, including asthma, water contamination, exposures to fracking fluid, and exposure of workers to silica dust. They voiced specific concerns about parkinsonism, neuropathy, and kidney disease, and called for prospective toxicity studies.[2494]

- October 25, 2017 – Scientists and physicians (including two co-authors of this *Compendium*) reviewed the body of evidence on the potential of unconventional oil and natural gas (UOG) development and operations to contribute to neurological and developmental harm via increased air and water pollution in the surrounding communities where it takes place. Highlighting data gaps and research limitations (such as the nondisclosure by industry of chemical mixtures), they nevertheless pinpointed evidence in the existing literature showing that "the chemicals that are used in or are byproducts of UOG operations have been linked to serious neurodevelopmental health problems in infants."[2495] Interviewed by the *Guardian,* a co-author said, "Given the profound sensitivity of the developing brain and the central nervous system, it is very reasonable to conclude that young children who experience frequent exposure to these pollutants are at particularly high risk for chronic neurological problems and disease."[2496]

[2491] Steve Scauzillo, "Living near Oil Wells Can Cause Health Problems, LA County Believes It Has Solutions," *Los Angeles Daily News*, February 28, 2018, https://www.dailynews.com/2018/02/27/living-near-oil-wells-can-cause-health-problems-la-county-believes-it-has-solutions/.
[2492] Northern Territory of Australia, "Draft Final Report of the Scientific Inquiry Into Hydraulic Fracturing in the Northern Territory," Draft Final Report (Government of Australia, January 30, 2018), https://frackinginquiry.nt.gov.au/inquiry-reports?a=479268.
[2493] Reuters Staff, "Study Seen Needed before Lifting Fracking Ban in Remote Australia," *Reuters*, December 12, 2017, sec. Environment, https://www.reuters.com/article/us-australia-fracking-idUSKBN1E60TL.
[2494] Russell A. Wilke and Jerome W. Freeman, "Potential Health Implications Related to Fracking," *JAMA* 318, no. 17 (2017): 1645, https://doi.org/10.1001/jama.2017.14239.
[2495] Ellen Webb et al., "Neurodevelopmental and Neurological Effects of Chemicals Associated with Unconventional Oil and Natural Gas Operations and Their Potential Effects on Infants and Children," *Reviews on Environmental Health* 33, no. 1 (2018): 3–29, https://doi.org/10.1515/reveh-2017-0008.
[2496] Nicola Davis, "Pollutants from Fracking Could Pose Health Risk to Children, Warn Researchers," *The Guardian*, October 25, 2017, sec. Environment, https://www.theguardian.com/environment/2017/oct/25/pollutants-from-fracking-could-pose-health-risk-to-children-warn-researchers.

The research team concluded that there is "a need for public health prevention techniques, well-designed studies, and stronger state and national regulatory standards."

- October 23, 2017 – A Yale University research team reported that carcinogens involved in fracking operations have the potential to contaminate both air and water in nearby communities in ways that may increase the risk of childhood leukemia. The team identified 55 known or possible carcinogens that may be released into air and water from fracking operations. Of these, 20 are linked to leukemia or lymphoma.[2497] "This analysis creates a priority list of carcinogens to target for future exposure and health studies."[2498]

- July 31, 2017 – A review by a team of medical, psychological, occupational, and environmental health professionals concluded, "there appears to be an array of levels of psychosocial functioning that are deleteriously affected by the fracking process and industries and their aftermath." Though much of the research they identified linking fracking to psychological functioning was preliminary, documented impacts included: individual-level impacts, such as feelings of stress and powerlessness; community-level impacts, such as disrupted social fabric and new gender/sex imbalances in the community; collective trauma such as caused by a boom-and-bust cycle; and worker impacts, such as psychosocial impacts of being a transient worker. The review provided "an important first step in understanding the psychological toll that this energy development strategy has on fracking communities and sets the stage for advancements in research, clinical and policy, that will help us to better understand, assist, and advocate for those affected by fracking."[2499]

- May 1, 2017 – The Southwest Pennsylvania Environmental Health Project established a voluntary public health registry "aimed at tracking and eventually analyzing the impacts of shale gas development on people living near wells, impoundments, compressor stations and pipelines." According to a spokesperson, "The point is that the vast majority of independent science is looking at [shale gas development] and saying something's not good there. We need to know more… The findings of this registry will allow the health care community to be more informed about what problems people are experiencing when they walk into their offices. It will give the doctors some idea of what they should be looking for."[2500]

- April 28, 2017 – Portuguese and Brazilian reviewers identified the issue of water resources "as one of the most sensitive to negative impacts by shale gas exploration and

[2497] Elise G. Elliott et al., "Unconventional Oil and Gas Development and Risk of Childhood Leukemia: Assessing the Evidence," *Science of The Total Environment* 576 (2017): 138–47, https://doi.org/10.1016/j.scitotenv.2016.10.072.
[2498] Denise Meyer, "Fracking Linked to Cancer-Causing Chemicals, New YSPH Study Finds," *Yale News*, October 24, 2016, https://ysph.yale.edu/news-article/fracking-linked-to-cancer-causing-chemicals-new-ysph-study-finds/.
[2499] Jameson K. Hirsch et al., "Psychosocial Impact of Fracking: A Review of the Literature on the Mental Health Consequences of Hydraulic Fracturing," *International Journal of Mental Health and Addiction* 16, no. 1 (2018): 1–15, https://doi.org/10.1007/s11469-017-9792-5.
[2500] Don Hopey, "Registry Will Study Health Impact from Living near Shale Gas Wells," *Pittsburgh Post-Gazette*, May 1, 2017, https://www.post-gazette.com/business/powersource/2017/05/01/Registry-will-study-health-impact-from-living-near-shale-gas-wells/stories/201705010018.

exploitation," in their examination of scientific articles published between 2010 and 2015. They pointed to "expected" new legislation and industry practices for impact reductions but continued on to say that there are "no indications of a solution in the near future" for the problems of wastewater and greenhouse gas emissions.[2501]

- February 8, 2017 – Addressing the community health and safety harms linked with camps that house temporary workers in extractive industries, the British Columbia Ministry of Aboriginal Relations and Reconciliation funded a research project carried out in consultation with Indigenous nations. The premise, that "Indigenous women and youth can experience negative impacts of resource extraction at every phase of resource development," was borne out by the project's community dialogues and literature review. "Increased domestic violence, sexual assault, substance abuse, and an increased incidence of sexually transmitted infections (STIs) and HIV/AIDS due to rape, prostitution, and sex trafficking are some of the recorded negative impacts of resource extraction projects, specifically as a result of the presence of industrial camps and transient work forces." The objectives of the project were to stimulate dialogue and to develop detailed protective steps for Nations, government, and industry in advance of the initiation of planned extraction projects in the region, such as the TransCanada and Spectra Energy pipelines, in order to prevent violence against women and other life changing negative effects linked to the industrial camps.[2502]

- February 8, 2017 – Los Angeles County health officials criticized as insufficient the allocation of only one million dollars by the Southern California Gas Company to fund an independent health study in the aftermath of the massive methane leak at Aliso Canyon that lasted from October 2015 until February 2016. "'It's a study, but not a health study,' said Angelo Bellomo, the Los Angeles County deputy director for health protection. 'It is not responsive to addressing the health needs and concerns to this community. More importantly, it's inconsistent with advice given to [South Coast Air Quality Management District] by health officials.'" Health experts from across the state had suggested a design "that was comprehensive and larger in scope as well as consistent with a state Senate bill introduced last year that estimated such a design would cost $13 million in the first three years, and up to $40 million to complete."[2503]

- January 19, 2017 – An epidemiologist at Brown University reviewed studies to date on health outcomes in communities living close to unconventional natural gas development, and identified areas requiring further study. "Future epidemiologic studies should implement personal exposure assessments to examine associations between individual

[2501] Daniele Costa et al., "Extensive Review of Shale Gas Environmental Impacts from Scientific Literature (2010–2015)," *Environmental Science and Pollution Research* 24, no. 17 (2017): 14579–94, https://doi.org/10.1007/s11356-017-8970-0.
[2502] G. Gibson et al., "Indigenous Communities and Industrial Camps: Promoting Healthy Communities in Settings of Industrial Change" (The Firelight Group with Lake Babine Nation and Nak'azdli Whut'en, 2017), https://firelight.ca/wp-content/uploads/2016/03/Firelight-work-camps-Feb-8-2017_FINAL.pdf.
[2503] Brenda Gazzar and Susan Abram, "$1 Million Health Study 'Shortchanges' Porter Ranch Gas Leak Victims, Critics Say," *Daily News*, February 8, 2017, https://www.dailynews.com/business/20170208/1-million-health-study-shortchanges-porter-ranch-gas-leak-victims-critics-say.

contaminants and relevant health outcomes, particularly to explain associations seen with respiratory and birth outcomes," the author concluded."[2504]

- December 5, 2016 – A team of British scientists wrote a 156-paper review on the risks and harms of fracking that attempts to "capture, review and interpret the published literature across all the accepted domains of public health in a systematic way and consider specific implications for the UK." They concluded that shale gas fracking "unequivocally presents an exposure hazard," and that further studies were needed to address exposure and health outcome data, noting the lack of before, during, and after exposure data for both air and water around drilling and fracking sites. Authors also noted that the claims that shale gas is less harmful to the climate than coal are not backed by lifecycle analyses. This team called for more research and a delay on any proposed drilling and fracking activity in the United Kingdom.[2505]

- November 1, 2016 – The government of Scotland released a health impact assessment that reconfirmed the evidence for potential contamination of air and water, threats to worker health from silica dust exposure, and risks to the health of nearby residents.[2506]

- October 23, 2016 – In a unanimous vote of the society's 300-member House of Delegates, the Pennsylvania Medical Society called for a moratorium on new shale gas drilling and fracking in Pennsylvania and an initiation of a health registry in communities with pre-existing operations.[2507, 2508]

- October 11, 2016 – A group of health care professionals in Massachusetts called for an immediate moratorium on major new natural gas infrastructure until the impact of these projects on the health of the communities affected can be adequately determined through a Comprehensive Health Impact Assessment.[2509] The group noted that the operation of natural gas facilities risks human exposures to toxic, cancer-causing, and radioactive pollution due to the presence of naturally co-occurring contaminants, toxic additives to the hydraulic fracturing process, and through the operation of transmission pipelines.[2510]

[2504] Shaina L. Stacy, "A Review of the Human Health Impacts of Unconventional Natural Gas Development," *Current Epidemiology Reports* 4, no. 1 (2017): 38–45, https://doi.org/10.1007/s40471-017-0097-9.
[2505] Patrick J. Saunders et al., "A Review of the Public Health Impacts of Unconventional Natural Gas Development," *Environmental Geochemistry and Health* 40, no. 1 (2018): 1–57, https://doi.org/10.1007/s10653-016-9898-x.
[2506] Health Protection Scotland, "A Health Impact Assessment of Unconventional Oil and Gas in Scotland: Volume 1 – Full Report," 2016, https://www.hps.scot.nhs.uk/web-resources-container/a-health-impact-assessment-of-unconventional-oil-and-gas-in-scotland-volume-1-full-report/.
[2507] Pennsylvania Medical Society, "Resolution 16-206: Pennsylvania Medical Society Support for a Moratorium on Fracking," October 23, 2016, https://www.pamedsoc.org/docs/librariesprovider2/pamed-documents/pamed-downloads/HODAEC/16-206.pdf.
[2508] Don Hopey, "Doctors Call for State Ban on Drilling and Fracking," *Pittsburgh Post-Gazette*, October 27, 2016, https://www.post-gazette.com/local/region/2016/10/27/Doctors-group-calls-for-moratorium-on-fracking-in-Pennsylvania/stories/201610270226.
[2509] Massachusetts Health Care Professionals Against Fracked Gas, "Call for a Moratorium on Natural Gas Projects Undergoing Construction or Review in the Commonwealth of Massachusetts," October 2016.
[2510] Massachusetts Health Care Professionals Against Fracked Gas, "The Role of Comprehensive Health Impact Assessment in Evaluating Natural Gas Infrastructure Proposals in Massachusetts," February 20, 2016.

- September 15, 2016 – A systematic review of 45 studies, primarily but not exclusively addressing conventional oil and gas activities, showed an emerging body of evidence documenting harm to reproductive health from residential and occupational exposure to these operations. The strongest evidence existed for increased risk of miscarriage, prostate cancer, birth defects, and decreased semen quality. Authors state that there is "ample evidence for disruption of the estrogen, androgen, and progesterone receptors with individual chemicals and waste products related to oil and gas extraction," and "impacts from unconventional oil and gas activities will likely be greater, given that unconventional activities have many similarities to conventional ones and employ dozens of endocrine-disrupting chemicals in the process of hydraulic fracturing."[2511]

- September 14, 2016 – In a commentary about fracking in the *American Journal of Public Health*, Weill Cornell Medicine physicians wrote, "mounting empirical evidence shows harm to the environment and to human health . . . and we have no idea what the long-term effects might be. . . . Ignoring the body of evidence, to us, is not a viable option anymore."[2512]

- July 7, 2016 –The UK health professional organization Medact released an updated assessment of the potential health impacts of shale fracking in England that confirm the findings of its 2015 report, *Health and Fracking*. The new report, *Shale Gas Production in England,* concluded, "Our view that the UK should abandon its policy to encourage [shale gas production] remains unchanged." The new report included hundreds of new academic papers addressing impacts on air and water quality, health, climate change, social wellbeing, economics, noise and light pollution, and seismic events. Still, authors wrote, "the absence of an independent social, health and economic impact assessment of [shale gas production] at scale is a glaring omission. Given the availability of alternative sources of energy, these are grounds for placing an indefinite moratorium on SGP (a position adopted by many jurisdictions across the world) until such time that there is greater clarity and certainty about the relative harms and benefits of shale gas."[2513]

- May 31, 2016 – "There are too many science, technology and risk-assessment gaps to green-light fracking in western Newfoundland," according to a panel that studied the question. In an interview with Canada's *Globe and Mail*, panel leader and engineering professor Ray Gosine said, "The science, the studies that have been done, have been somewhat limited – certainly limited compared to what we'd expect to have done in order

[2511] Victoria D. Balise et al., "Systematic Review of the Association between Oil and Natural Gas Extraction Processes and Human Reproduction," *Fertility and Sterility* 106, no. 4 (2016): 795–819, https://doi.org/10.1016/j.fertnstert.2016.07.1099.
[2512] Madelon L. Finkel and Adam Law, "The Rush to Drill for Natural Gas: A Five-Year Update," *American Journal of Public Health* 106, no. 10 (2016): 1728–30, https://doi.org/10.2105/AJPH.2016.303398.
[2513] David McCoy and Alice Munro, "Shale Gas Production in England - an Updated Public Health Assessment" (MedAct Health Professionals for a Safer, Fairer, & Better World, July 7, 2016), https://www.medact.org/2016/resources/reports/shale-gas-production-in-england/.

to plan this kind of operation…. There are a number of gaps and deficiencies that are significant."[2514]

- May 13, 2016 – Physicians for Social Responsibility called for a ban on hydraulic fracturing, pointing both to the irremediable climate harm caused by methane emissions as well to the multiple health risks from industrial-scale water consumption, air pollution, seismic effects, the generation of large quantities of toxic liquid waste, and long-term impacts on drinking water aquifers. "We cannot stay healthy in an unhealthy environment. Nor can we survive indefinitely on a planet growing hotter and more prone to extreme, unpredictable and destructive weather. These factors impel PSR to call for a ban on fracking and for a rapid transition to cleaner, healthier, carbon-free sources of energy."[2515]

- March 27, 2016 – Noting that many chemicals used in fracking fluids are known or suspected endocrine disruptors, a group of public health researchers called for an endocrine-centric component for health assessments in areas impacted by oil and gas operations. The team outlined a series of recommendations to assess the "potential endocrine-related risks from chemical exposures associated with oil and natural gas operations. We present these recommendations in light of the growing body of information regarding both chemical concentrations in the environment and adverse health outcomes reported in humans and wildlife."[2516]

- November 24, 2015 – A Harvard University team identified a trend toward increasing chemical secrecy and less transparency by examining 96,000 chemical disclosure forms filed by fracking companies between March 2011 and April 2015. These forms were submitted to the Fracfocus website, a chemical disclosure portal for the fracking industry that operates on a voluntary basis but for which reporting in mandated in more than 20 states. Fracfocus is the largest public database on chemicals used in U.S. fracking operations.[2517] Companies involved in fracking withheld chemical data at significantly higher rates in 2015 (16.5 percent) as compared to 2011-2013 (11 percent). The research team also found that withholding drops by a factor of four when companies report aggregate data without attribution to the specific products in the fracking fluid. The authors called for state governments to retain authority in requiring disclosure of "product-specific ingredient lists."[2518]

[2514] Sue Bailey, "Too Many Gaps to Recommend Fracking in Newfoundland: Panel," *The Globe and Mail*, May 31, 2016, https://www.theglobeandmail.com/report-on-business/industry-news/energy-and-resources/too-many-unknowns-to-recommend-fracking-in-western-newfoundland-panel/article30216746/.
[2515] Physicians for Social Responsibility, "PSR Position Statement on Hydraulic Fracturing," Physicians for Social Responsibility, May 13, 2016, https://www.psr.org/blog/resource/psr-position-statement-on-hydraulic-fracturing/.
[2516] Christopher D. Kassotis et al., "Endocrine-Disrupting Chemicals and Oil and Natural Gas Operations: Potential Environmental Contamination and Recommendations to Assess Complex Environmental Mixtures," *Environmental Health Perspectives* 124, no. 3 (2016): 256–64, https://doi.org/10.1289/ehp.1409535.
[2517] Lisa Song, "What Chemicals Are Used in Fracking? Industry Discloses Less and Less," *Inside Climate News*, November 24, 2015, https://insideclimatenews.org/news/24112015/fracking-natural-gas-drilling-chemicals-frac-focus-study/.
[2518] Katherine Konschnik and Archana Dayalu, "Hydraulic Fracturing Chemicals Reporting: Analysis of Available Data and Recommendations for Policymakers," *Energy Policy* 88 (2016): 504–14, https://doi.org/10.1016/j.enpol.2015.11.002.

- August 7, 2015 – While acknowledging the "dramatic increase in the number of peer-reviewed published studies" on environmental and health impacts of fracking, Weill Cornell Medical College's Dr. Madelon Finkel and co-author PSE Healthy Energy's Jake Hays called for more well-designed longer-term epidemiologic studies to quantify the connections between fracking-related risk factors and health outcomes. Without such studies it is challenging to capture, for example, outcomes such as cancer that take many years to present. The authors described several important studies that are currently underway that will add to the body of knowledge in the future.[2519]

- June 9, 2015 – Information on individual exposures and local environmental conditions prior to the commencement of fracking in a given area is often "unavailable or hard to obtain. These and other data gaps have hindered the kind of large-scale epidemiological studies that can link exposures to actual health outcomes, with valid comparison groups," wrote public health journalist David Tuller in the journal *Health Affairs*.[2520] In an interview with *Michigan Radio*, Tuller noted that, because well development happens quickly, there was generally a lack of pre-drilling baseline studies.[2521]

- April 17, 2015 – Using sophisticated Geographic Information Systems (GIS) tools to examine distribution of fracking wells compared to distribution of vulnerable populations, Clark University researchers found consistent evidence that, in the Pennsylvania Marcellus Shale region, census tracts with potential exposure to pollution from fracking wells contained "significantly higher" percentages of poor people. They also found clusters of vulnerable populations concentrated near drilling and fracking in all three states they studied: Pennsylvania (for poverty and elderly population), West Virginia (for poverty, elderly population, and education level) and Ohio (for children). Researchers also reported difficulty in accessing high quality and consistent unconventional well data in all three states, demonstrating an "urgent need" for common data collection and reporting.[2522] Another GIS-based study sought to begin to fill this gap in data on spatially distributed risks of fracking, identifying Pennsylvania populations at "very high" and "high" risk in over a dozen counties. The author called for more focus on those areas to understand the impacts of fracking.[2523]

[2519] Madelon L. Finkel and Jake Hays, "Environmental and Health Impacts of 'Fracking': Why Epidemiological Studies Are Necessary," *Journal of Epidemiology and Community Health* 70, no. 3 (2016): 221–22, https://doi.org/10.1136/jech-2015-205487.
[2520] David Tuller, "As Fracking Booms, Dearth Of Health Risk Data Remains," *Health Affairs (Project Hope)* 34, no. 6 (June 2015): 903–6, https://doi.org/10.1377/hlthaff.2015.0484.
[2521] Rebecca Williams, "Why There Are Gaps in Public Health Studies on Fracking," Michigan Radio, June 9, 2015, https://www.michiganradio.org/environment-science/2015-06-09/why-there-are-gaps-in-public-health-studies-on-fracking.
[2522] Ogneva-Himmelberger and Huang, "Spatial Distribution of Unconventional Gas Wells and Human Populations in the Marcellus Shale in the United States: Vulnerability Analysis."
[2523] Qingmin Meng, "Spatial Analysis of Environment and Population at Risk of Natural Gas Fracking in the State of Pennsylvania, USA," *The Science of the Total Environment* 515–516 (2015): 198–206, https://doi.org/10.1016/j.scitotenv.2015.02.030.

- March 30, 2015 – The UK medical organization Medact published a report, *Health & Fracking: The Impacts and Opportunity Costs*, which concluded that fracking poses significant risks to public health and called for an immediate moratorium to allow time for a full and comprehensive health and environmental impact assessment to be completed.[2524] The report was supported by a letter published in the *British Medical Journal* calling for shale gas development to be put on hold, signed by the Climate and Health Council and over a dozen senior health professionals. The letter stated, "The arguments against fracking on public health and ecological grounds are overwhelming. There are clear grounds for adopting the precautionary principle and prohibiting fracking."[2525]

- February 17, 2015 – Writing in the *Canadian Medical Association Journal*, a public health scientist and medical doctor briefly reviewed the human health risks of fracking documented to date and made the case for a health care worker role in insisting on improved understanding. They cited worker and community safety issues as the biggest short-term risks, but emphasized that more needs to be known "before health care providers can definitively respond to their patients' and communities' concerns.… Physicians may wish to advocate delaying new development activities until the potential health effects are better understood."[2526]

- January 22, 2015 –The acting head of research at the Cancer Association of South Africa, Carl Albrecht, said that known carcinogenic chemicals used in fracking could lead to an epidemic of cancer in South Africa's Karoo desert. As South Africa was poised to publish draft regulations, Albrecht said that the effect of fracking on human health was ignored.[2527]

- January 19, 2015 – In an article that reviewed research and research gaps, a team of British and U.S. medical and scientific professionals urged the United Kingdom and other nations to engage in science before engaging in fracking. They warned that even strong regulations may not effectively address air pollution from fracking, and that "permanent, adverse environmental, climatic, and population health impacts" may exist in some cases.[2528]

[2524] David McCoy and Patrick Saunders, "Health & Fracking: The Impacts and Opportunity Costs" (MedAct Health Professionals for a Safer, Fairer, & Better World, 2015), https://www.medact.org/2015/resources/reports/health-and-fracking/.
[2525] Robin Stott et al., "Public Health England's Draft Report on Shale Gas Extraction," *BMJ* 348 (2014): g2728, https://doi.org/10.1136/bmj.g2728.
[2526] Lalita Bharadwaj and Bernard D. Goldstein, "Shale Gas Development in Canada: What Are the Potential Health Effects?," *CMAJ : Canadian Medical Association Journal* 187, no. 3 (2015): E99–100, https://doi.org/10.1503/cmaj.140599.
[2527] Paul Vecchiatto, "Chemicals Used in Fracking 'Could Cause Cancer'," *Business Day BDLive*, January 22, 2015, https://web.archive.org/web/20150124035808/http://www.bdlive.co.za/business/energy/2015/01/22/chemicals-used-in-fracking-could-cause-cancer.
[2528] Jake Hays et al., "Considerations for the Development of Shale Gas in the United Kingdom," *Science of The Total Environment* 512–513 (2015): 36–42, https://doi.org/10.1016/j.scitotenv.2015.01.004.

- December 17, 2014 – In an editorial, Rutgers University environmental exposure expert Paul J. Lioy (now deceased) highlighted fracking as an area in which accurate exposure monitoring and risk assessment did not yet exist. Lioy emphasized that the relevant research was compartmentalized and fragmented and that exposures and health outcomes around unconventional natural gas development need to be systematically addressed through "well-defined exposure studies in communities and workplaces."[2529]

- December 5, 2014 – A team of medical and scientific researchers, including from the Institute for Health and Environment at the State University of New York (SUNY) at Albany, reviewed the scientific evidence that both adult and early life—including prenatal—exposure to chemicals from fracking operations can result in adverse reproductive health and developmental effects. These include: endocrine-disrupting chemicals potentially increasing risk for reproductive problems, breast cancer, abnormal growth and developmental delays, and changes in immune function; benzene, toluene and xylene (BTX chemicals) increasing risk for impaired sperm quantity and quality in men and menstrual and fertility problems in women; and heavy metals increasing the risk of miscarriage and/or stillbirths. Potential exposures occur through both air and water. Based on their review, the authors concluded, "Taken together, there is an urgent need for the following: 1) biomonitoring of human, domestic and wild animals for these chemicals; and 2) systematic and comprehensive epidemiological studies to examine the potential for human harm."[2530] Lead author Susan Nagel said in an accompanying interview, "We desperately need biomonitoring data from these people. What are people actually exposed to? What are the blood levels of people living in these areas? What are the levels in the workers?"[2531]

- November 12, 2014 – A team of Australian researchers reviewed the strength of evidence for environmental health impacts of fracking based on publications from 1995 to 2014. They noted that the rapid expansion of fracking had outstripped the pace of science and that most studies focused on short-term, rather than long-term, health. Hence, "very few studies examined health outcomes with longer latencies such as cancer or developmental outcomes." Noting that no evidence exists to rule out health impacts, the team called for direct and clear public health assessments before projects are approved, longitudinal studies that include baseline data, and government and industry transparency.[2532]

[2529] Paul J. Lioy, "Exposure Science and Its Places in Environmental Health Sciences and Risk Assessment: Why Is Its Application Still an Ongoing Struggle in 2014?," *Journal of Exposure Science & Environmental Epidemiology* 25, no. 1 (2015): 1–3, https://doi.org/10.1038/jes.2014.59.

[2530] Ellen Webb et al., "Developmental and Reproductive Effects of Chemicals Associated with Unconventional Oil and Natural Gas Operations," *Reviews on Environmental Health* 29, no. 4 (2014), https://doi.org/10.1515/reveh-2014-0057.

[2531] Ian Sample, "Fracking Chemicals Could Pose Risks to Reproductive Health, Say Researchers," *The Guardian*, December 5, 2014, sec. Environment, https://www.theguardian.com/environment/2014/dec/05/fracking-chemicals-could-pose-risks-to-reproductive-health-say-researchers.

[2532] Angela K. Werner et al., "Environmental Health Impacts of Unconventional Natural Gas Development: A Review of the Current Strength of Evidence," *Science of The Total Environment* 505 (2015): 1127–41, https://doi.org/10.1016/j.scitotenv.2014.10.084.

- September 15, 2014 – Researchers led by University of Rochester's Environmental Health Sciences Center conducted interviews in New York, North Carolina, and Ohio to evaluate community health concerns about unconventional natural gas development. They identified many areas where more study is needed, including baseline measures of air quality, ongoing environmental monitoring, and health impact assessments. They noted that other areas where data are lacking involve the assessment of drilling and fracking impacts on vulnerable populations such as very young children, and the potential consequences of interactions between exposures resulting from shale gas extraction operations. Researchers suggested incorporating the input of potentially affected community members into the development of the research agenda.[2533]

- July 21, 2014 – An independent assessment report by Scientists for Global Responsibility and the Chartered Institute of Environmental Health reviewed current evidence across a number of issues associated with shale gas extraction by hydraulic fracturing, including environmental and public health risks, drawing on academic research. Among the report's conclusions: there are major shortcomings in regulatory oversight regarding local environmental and public health risks; there is a large potential for UK shale gas exploitation to undermine national and international efforts to tackle climate change; the water-intensive nature of the fracking process which could cause water shortages in many areas; the complete lack of evidence behind claims that shale gas exploitation will bring down UK energy bills; and concerns that it will impact negatively on UK energy security. Despite claims to the contrary, the report noted that evidence of local environmental contamination from shale gas exploitation is well reported in the scientific literature. It emphasizes that, "[t]here are widespread concerns over the lack of evidence on fracking-related health impacts," and that there is a lack of "substantive epidemiological study for populations exposed to shale gas extraction."[2534]

- July 18, 2014 – A working group of the Environmental Health Sciences Core Centers, supported by the National Institute of Environmental Health Sciences, reviewed the available literature on the potential health impacts of fracking for natural gas. They concluded that further research is urgently needed. Needs identified included: monitoring of air and water quality over the entire lifetime of wells; further epidemiologic research addressing health outcomes and water quality; and research addressing whether air pollution associated with fracking increases the risk of pulmonary and cardiovascular disease. The working group advocated for the participation of potentially affected communities in all areas of research.[2535]

[2533] Katrina Smith Korfmacher, Kathleen M. Gray, and Erin Haynes, "Health Impacts of Unconventional Natural Gas Development: A Comparative Assessment of Community Information Needs in New York, North Carolina, and Ohio," Final Project Report, September 15, 2014.
[2534] Gwen Harrison and Stuart Parkinson, "Shale Gas and Fracking: Examining the Evidence" (Scientists for Global Responsibility & the Chartered Institute of Environmental Health, July 2014), https://www.sgr.org.uk/sites/sgr.org.uk/files/SGR-CIEH-Shale-gas-bfg.pdf.
[2535] Trevor M. Penning et al., "Environmental Health Research Recommendations from the Inter-Environmental Health Sciences Core Center Working Group on Unconventional Natural Gas Drilling Operations," *Environmental Health Perspectives* 122, no. 11 (2014): 1155–59, https://doi.org/10.1289/ehp.1408207.

- July 12, 2014 – Eli Avila, Pennsylvania's former Secretary of Health, said that health officials need to be proactive in protecting the public from the health effects of unconventional shale gas extraction. In 2011, funding was approved for a Pennsylvania public health registry to track drilling related complaints and address concerns, but was cut at the last minute. Speaking to the problem posed by the dearth of information, Avila asked, "How can you keep the public safe if you're not collecting data?"[2536]

- June 30, 2014 – The immediate past chair of the Executive Committee of the Council on Environmental Health for the American Academy of Pediatrics, Jerome A. Paulson, MD, called for industry disclosure of all ingredients of fracking fluid; thorough study of all air contaminants released from drilling and fracking operations and their protected dispersal patterns; and study and disclosure of fracking-related water contamination and its mechanisms. In a letter to the Pennsylvania Department of Environmental Protection (PA DEP), Paulson said:

  > In summary, neither the industry, nor government agencies, nor other researchers have ever documented that [unconventional gas extraction] can be performed in a manner that minimizes risks to human health. There is now some evidence that these risks that many have been concerned about for a number of years are real risks. There is also much data to indicate that there are a number of toxic chemicals used or derived from the process, known or plausible routes of exposure of those chemicals to humans; and therefore, reason to place extreme limits on [unconventional gas extraction].[2537]

- June 20, 2014 – Highlighting preliminary studies in the United States that suggest an increased risk of adverse health problems among individuals living within ten miles of shale gas operations, a commentary in the British medical journal *The Lancet* called for a precautionary approach to gas drilling in the United Kingdom. According the commentary, "It may be irresponsible to consider any further fracking in the UK (exploratory or otherwise) until these prospective studies have been completed and the health impacts of fracking have been determined."[2538]

- June 20, 2014 – Led by an occupational and environmental medicine physician, a Pennsylvania-based medical and environmental science research team documented "… the substantial concern about adverse health effects of [unconventional natural gas development] among Pennsylvania Marcellus Shale residents, and that these concerns may not be adequately represented in medical records." The teams identified the continued need to pursue environmental, clinical, and epidemiological studies to better

[2536] Kevin Begos, "Expert: Pa. Didn't Address Fracking Health Impacts," *Observer-Reporter*, July 12, 2014, https://observer-reporter.com/news/regional/expert-pa-didn-t-address-fracking-health-impacts/article_88d539c7-cb17-56a5-95df-b19887246e60.html.
[2537] Jerome A. Paulson, "Letter to the Pennsylvania Department of Environmental Protection," June 30, 2014, https://concernedhealthny.org/2014/06/letter-from-dr-jerome-a-paulson-to-the-pennsylvania-department-of-environmental-protection/.
[2538] Michael Hill, "Shale Gas Regulation in the UK and Health Implications of Fracking," *The Lancet* 383, no. 9936 (2014): 2211–12, https://doi.org/10.1016/S0140-6736(14)60888-6.

understand associations between fracking, medical outcomes, and residents' ongoing concerns.[2539]

- June 17, 2014 – A discussion paper by the Nova Scotia Deputy Chief Medical Officer and a panel of experts identified potential economic benefits as well as public health concerns from unconventional oil and gas development. On the health impacts, they wrote, "uncertainties around long term environmental effects, particularly those related to climate change and its impact on the health of both current and future generations, are considerable and should inform government decision making…" The report noted potential dangers including contamination of groundwater, air pollution, surface spills, increased truck traffic, noise pollution, occupational health hazards, and the generation of greenhouse gases. It also noted that proximity of potential fracking sites to human habitation should give regulators pause and called for a health impact assessment and study of long-term impacts.[2540] Responding to the report, the Environmental Health Association of Nova Scotia applauded the go-slow approach and called for a 10-year moratorium on fracking.[2541]

- May 29, 2014 – In New York State, more than 250 medical organizations and health professionals released a letter detailing emerging trends in the data on fracking that show significant risk to public health, air quality, and water, as well as other impacts. With signatories including the American Academy of Pediatrics, District II, the American Lung Association in New York, Physicians for Social Responsibility, and many leading researchers examining the impacts of fracking, they wrote, "The totality of the science — which now encompasses hundreds of peer-reviewed studies and hundreds of additional reports and case examples—shows that permitting fracking in New York would pose significant threats to the air, water, health and safety of New Yorkers."[2542, 2543]

- May 9, 2014 – In a peer-reviewed analysis, leading toxicologists outlined some of the potential harm and uncertainty relating to the toxicity of the chemical and physical agents associated with fracking, individually and in combination. While acknowledging the need for more research and greater involvement of toxicologists, they noted the potential for surface and groundwater contamination from fracking, growing concerns about air

[2539] Pouné Saberi et al., "Field Survey of Health Perception and Complaints of Pennsylvania Residents in the Marcellus Shale Region," *International Journal of Environmental Research and Public Health* 11, no. 6 (2014): 6517–27, https://doi.org/10.3390/ijerph110606517.
[2540] Frank Atherton et al., "Report of the Nova Scotia Independent Review Panel on Hydraulic Fracturing" (Cape Breton University, 2014).
[2541] Michael MacDonald, "N.S. Expert Calls for Go-Slow Approach for Fracking," *CTV News*, June 17, 2014, https://atlantic.ctvnews.ca/n-s-expert-calls-for-go-slow-approach-for-fracking-1.1872529.
[2542] Concerned Health Professionals of NY, "Letter to Governor Cuomo and Acting Health Commissioner Howard A. Zucker," Concerned Health Professionals of NY, May 29, 2014, https://concernedhealthny.org/letters-to-governor-cuomo/.
[2543] Kyle Hughes, "NY Fracking Opponents Call for Moratorium of 3 to 5 Years," *Daily Freeman*, May 29, 2014, https://www.dailyfreeman.com/news/ny-fracking-opponents-call-for-moratorium-of-3-to-5-years/article_f1383150-da0d-5291-973f-461498241056.html.

pollution particularly in the aggregate, and occupational exposures that pose a series of potential hazards to worker health.[2544, 2545]

- May 1, 2014 – A 292-page report from a panel of top Canadian scientists urged caution on fracking, noting that it poses "the possibility of major adverse impacts on people and ecosystems" and that significantly more study is necessary to understand the full extent of the risks and impacts.[2546] The *Financial Post* reported that the panel of experts "found significant uncertainty on the risks to the environment and human health, which include possible contamination of ground water as well as exposure to poorly understood combinations of chemicals."[2547]

- April 30, 2014 – Medical professionals spoke out on the dearth of public health information collected and lack of long-term study five years into Pennsylvania's fracking boom. Walter Tsou, MD, MPH, past president of the American Public Health Association and former Health Commissioner of Philadelphia commented, "That kind of study from a rigorous scientific perspective has never been done." Other experts added, "There has been more health research involving fracking in recent years, but every study seems to consider a different aspect, and … there is no coordination."[2548]

- April 17, 2014 – In the preeminent *British Medical Journal*, authors of a commentary, including an endocrinologist and a professor of clinical public health, wrote, "Rigorous, quantitative epidemiological research is needed to assess the risks to public health, and data are just starting to emerge. As investigations of shale gas extraction in the US have continually suggested, assurances of safety are no proxy for adequate protection."[2549]

- April 15, 2014 – The *Canadian Medical Association Journal* reported on the increasing legitimacy of concerns about fracking on health: "While scientists and area residents have been sounding the alarm about the health impacts of shale gas drilling for years, recent studies, a legal decision and public health advocates are bringing greater legitimacy to concerns."[2550]

[2544] Society of Toxicology, "Toxicologists Outline Key Health and Environmental Concerns Associated with Hydraulic Fracturing," *ScienceDaily*, May 9, 2014, https://www.sciencedaily.com/releases/2014/05/140509172545.htm.
[2545] Bernard D. Goldstein et al., "The Role of Toxicological Science in Meeting the Challenges and Opportunities of Hydraulic Fracturing," *Toxicological Sciences* 139, no. 2 (2014): 271–83, https://doi.org/10.1093/toxsci/kfu061.
[2546] Council of Canadian Academies, "Environmental Impacts of Shale Gas Extraction in Canada: The Expert Panel on Harnessing Science and Technology to Understand the Environmental Impacts of Shale Gas Extraction."
[2547] The Canadian Press, "Top Canadian Scientists Urge Cautious Approach to Fracking until More Known of Impact," *Financial Post*, May 1, 2014, https://financialpost.com/commodities/energy/top-canadian-scientists-urge-cautious-approach-to-fracking-until-more-known-of-impact.
[2548] Natasha Khan, "Health Impact of Gas Fracking Left in the Dark," *Pocono Record*, April 30, 2014, https://www.poconorecord.com/article/20140430/NEWS90/404300301.
[2549] Adam Law et al., "Public Health England's Draft Report on Shale Gas Extraction," *BMJ* 348, no. apr17 6 (2014): g2728–g2728, https://doi.org/10.1136/bmj.g2728.
[2550] Wendy Glauser, "New Legitimacy to Concerns about Fracking and Health," *Canadian Medical Association Journal* 186, no. 8 (2014): E245–46, https://doi.org/10.1503/cmaj.109-4725.

- March 3, 2014 – In the *Medical Journal of Australia*, researchers and a physician published a strongly worded statement, "Harms unknown: health uncertainties cast doubt on the role of unconventional gas in Australia's energy future." They cited knowledge to date on air, water, and soil pollution, and expressed concern about "environmental, social and psychological factors that have more indirect effects on health, and important social justice implications" yet to be understood. They wrote in summary:

  > The uncertainties surrounding the health implications of unconventional gas, when considered together with doubts surrounding its greenhouse gas profile and cost, weigh heavily against proceeding with proposed future developments. While the health effects associated with fracturing chemicals have attracted considerable public attention, risks posed by wastewater, community disruption and the interaction between exposures are of also of concern.[2551]

- March 1, 2014 – In the prestigious British medical journal *The Lancet*, researchers summarized workshops and research about the health impacts of fracking, noting that the scientific study on the health impacts of fracking is "in its infancy." Nevertheless, the existing evidence suggests, said these researchers, that health risks posed by fracking exceed those posed by conventional oil and gas wells due to the sheer number and density of well pads being developed, their proximity to densely populated areas, and the need to transport and store large volumes of materials.[2552]

- February 24, 2014 – In a review of the health effects of unconventional natural gas extraction published in the journal *Environmental Science & Technology*, leading researchers identified a range of impacts and exposure pathways that can be detrimental to human health. Noting how fracking disrupts communities, the review states, "For communities near development and production sites the major stressors are air pollutants, ground and surface water contamination, truck traffic and noise pollution, accidents and malfunctions, and psychosocial stress associated with community change." They concluded, "Overall, the current scientific literature suggests that there are both substantial public concerns and major uncertainties to address."[2553]

- August 30, 2013 – A summary of a 2012 workshop by the Institute of Medicine Roundtable on Environmental Health Sciences, Research, and Medicine featured various experts who discussed health and environmental concerns about fracking and the need for more research. The report in summary of the workshop stated, "The governmental public health system, which retains primary responsibility for health, was not an early participant in discussions about shale gas extraction; thus public health is lacking critical information about environmental health impacts of these technologies and is limited in its

[2551] Alicia Coram, Jeremy Moss, and Grant Blashki, "Harms Unknown: Health Uncertainties Cast Doubt on the Role of Unconventional Gas in Australia's Energy Future," *Medical Journal of Australia* 200, no. 4 (2014): 210–13, https://doi.org/10.5694/mja13.11023.
[2552] Sari Kovats et al., "The Health Implications of Fracking," *The Lancet* 383, no. 9919 (2014): 757–58, https://doi.org/10.1016/S0140-6736(13)62700-2.
[2553] Adgate, Goldstein, and McKenzie, "Potential Public Health Hazards, Exposures and Health Effects from Unconventional Natural Gas Development."

ability to address concerns raised by regulators at the federal and state levels, communities, and workers employed in the shale gas extraction industry."[2554]

- June 2013 – A group of three nursing professors published a cautionary review questioning the rollout of new shale-based energy practices at a time when, "anecdotal reports make clear that the removal of fossil fuels from the earth directly affects human health." Although the results of long-term studies are not yet available, the authors point to emerging evidence for negative human and ecologic health effects of fracking. Furthermore, they continue, "sufficient evidence has been presented to the [American Nurses Association], the American Public Health Association, and the American Medical Association's Resident and Fellow Section to result in a call for a moratorium on the issuance of new fracking permits nationally." They urge nurses to contribute to keeping health issues "front and center as we address national energy needs and policies."[2555]

- April 22, 2013 – In one of the first peer-reviewed nursing articles summarizing the known health and community risks of fracking, Professor Margaret Rafferty, Chair of the Department of Nursing at New York City College of Technology wrote, "Any initiation or further expansion of unconventional gas drilling must be preceded by a comprehensive Health Impact Assessment (HIA)."[2556]

- May 10, 2011 – In the *American Journal of Public Health*, two medical experts cautioned that fracking "poses a threat to the environment and to the public's health. There is evidence that many of the chemicals used in fracking can damage the lungs, liver, kidneys, blood, and brain." The authors urged that it would be prudent to invoke the precautionary principle in order to protect public health and the environment.[2557]

[2554] Christine Coussens and Rose Marie Martinez, "Health Impact Assessment of Shale Gas Extraction: Workshop Summary," in *Roundtable on Environmental Health Sciences, Research, and Medicine* (Institute of Medicine and the Board on Population Health and Public Health Practice, Washington, D.C., 2013), https://www.ncbi.nlm.nih.gov/books/NBK201904/.
[2555] Ruth McDermott-Levy, Nina Kaktins, and Barbara Sattler, "Fracking, the Environment, and Health: New Energy Practices May Threaten Public Health," *American Journal of Nursing* 113, no. 6 (2013): 45–51, https://doi.org/10.1097/01.NAJ.0000431272.83277.f4.
[2556] Margaret A. Rafferty and Elena Limonik, "Is Shale Gas Drilling an Energy Solution or Public Health Crisis?," *Public Health Nursing* 30, no. 5 (2013): 454–62, https://doi.org/10.1111/phn.12036.
[2557] Madelon L. Finkel and Adam Law, "The Rush to Drill for Natural Gas: A Public Health Cautionary Tale," *American Journal of Public Health* 101, no. 5 (2011): 784–85, https://doi.org/10.2105/AJPH.2010.300089.