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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COMPILATION OF STUDIES AND FINDINGS

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

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[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

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[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

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[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.)

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[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

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[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.