Exhibit 1

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2017 World LNG Report

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2. State of the LNG Industry[1]

258 MT
Global trade in 2016

Global Trade:For the third consecutive year, global LNG trade set a new record, reaching 258 million tonnes (MT). This marks an increase of 13.1 MT (+5%) from 2015, when a previous record of 244.8 MT was set over the 2014 trade volume of 241.1 MT. The growth rate in 2016 was a noticeable increase from the average growth of 0.5% over the last four years, when there were not very many new supply additions. The continued addition of supply in the Pacific Basin, primarily in Australia, as well as the start of exports from the United States Gulf of Mexico (US GOM) enabled this increase. Demand growth was most pronounced in Asia; China, India, and Pakistan added a combined 13.0 MT in incremental LNG demand. Inter-basin LNG trade flows have declined, particularly as Pacific Basin supplies continued to catch up with high demand in that region.

72 MT
Non long-term trade, 2016

Short and Medium-term LNG Market: Short and medium-term LNG trade reached 72.3 MT in 2016 (+0.4 MT YOY) and accounted for 28% of total trade. Historically, short and medium-term trade grew in 2011, owing to shocks that include the Fukushima crisis, which called on emergency cargos to help fill the power generation gap; and the growth of shale gas in the United States, which facilitated excess cargos no longer needed in a flush market. Both events added a need for commercial innovation and flexibility. However, the share of LNG traded without a long-term contract as a percentage of the global market has tapered off since 2013. Short and medium-term trade, as a share of total traded LNG, fell by 4%. Several emerging markets like Pakistan and Malaysia, seeking firm supply, began importing LNG under new long-term contracts in 2016. Other markets that typically rely heavily on spot and short-term volumes experienced a significant decline in demand. In the case of Brazil it was due to improved hydro-power availability. Further, the majority of new liquefaction projects that started operations in 2015 and 2016 in the Asia-Pacific region are supported by long-term contracts that are coming into force.

$5.52/MMBtu
Average Northeast Asian spot price, 2016

Global Prices: Asian and spot LNG prices fell steadily in the first half of 2016 as supply overwhelmed demand, settling at $4.05 per million British thermal units (MMBtu) in May. A reversal occurred in the second half of the year, with supply disruptions and cold winter temperatures driving spot prices to $9.95/MMBtu by February 2017. With cold weather and storage constraints at Rough, the United Kingdom National Balancing Point (NBP) also ended the year on an upswing at $5.44/MMBtu. The oil price continued to decline in the first half of the year resulting in low oil-indexed contract prices. As prices fell around the world, the market moved closer to price convergence; the differential between NBP and Northeast Asian spot prices narrowed to an average $0.91/MMBtu in 2016. Notably, the differential was negative for several months for the first time in six years. In May and June 2016, the Asian spot price was ~$0.40/MMBtu lower than NBP.

[1] The scope of this report is limited only to international LNG trade, excluding small-scale projects, unless explicitly stated. Small-scale projects are defined as anything less than 0.5 MTPA for liquefaction, 1.0 MTPA for regasification, and 60,000 cm for LNG vessels. Domestic movements of LNG are also not included.

340 MTPA
Global nominal liquefaction capacity, January 2017

Liquefaction plants: Global liquefaction capacity grew at a similar rate in 2016 as in 2015, adding 35 MTPA of capacity between end-2015 and January 2017 to reach 339.7 MTPA. This includes new projects such as Gorgon LNG, Australia Pacific LNG and Sabine Pass LNG, as well as additional trains at Gladstone LNG (GLNG), Queensland Curtis LNG (QCLNG), and Malaysia LNG (MLNG). Liquefaction capacity additions are poised to increase over the next few years as 114.6 MTPA of capacity was under-construction as of January 2017. Two projects entered the construction phase of development in 2016: a brownfield expansion of Tangguh LNG (3.8 MTPA) as well as an additional US project, Elba Island LNG (2.5 MTPA).

879 MTPA
Proposed liquefaction capacity, January 2017

New Liquefaction Proposals: Given abundant gas discoveries globally and the shale revolution in the US, proposed liquefaction capacity reached 890 million tonnes per annum (MTPA) by January 2016. This figure fell slightly to 879 MTPA at end-January 2017 in an attempt at rationalization with market demand. More of these projects will not go forward as demand remains far below this ambitious target; particularly as ample pipeline supply - by Russia and Norway to Europe, and the US to Mexico - reduce the need for LNG in those markets. Additionally, Egypt will experience a drastic reduction in LNG demand as the Zohr field comes on-line and preferentially supplies the domestic market. In fact, there is potential for Egypt to again be a significant LNG exporter. The areas with the largest proposed volumes include the US GOM, Canada, East Africa, and Asia-Pacific brownfield expansions.

795 MTPA
Global nominal regasification capacity, January 2017

Regasification Terminals: Global regasification capacity increased to 776.8 MTPA by the end of 2016 and 794.6 MTPA by the end of January 2017, primarily supported by additional capacity coming online in established markets such as China, Japan, France, India, Turkey, and South Korea. This stands in contrast with 2015, when capacity was driven by floating regasification projects in emerging markets: Egypt, Jordan, and Pakistan. The expansion of new markets slowed in 2016, as capacity was only added in Jamaica - both Colombia and Malta received their initial LNG cargoes in 2017. An additional 90.4 MTPA of capacity were under construction as of January 2017. A combined eleven projects are under construction in China and India, countries that displayed the strongest LNG demand growth in 2016. New entrants are also set to complete regasification projects in the coming years, including the Philippines, Bahrain, and Russia (Kaliningrad).

83 MTPA[2]
FSRU capacity, January 2017

Floating Regasification: Two floating storage and regasification units (FSRUs) located in the United Arab Emirates (Abu Dhabi – 3.8 MTPA) and Turkey (5.3 MTPA) reached commercial operations by January 2017, boosting global FSRU capacity to 83.0 MTPA. Floating regasification infrastructure was also added in Colombia (FSRU) and Malta (a floating storage unit) but neither had begun commercial operations by January 2017. This builds on the fast growth in 2015, when 17.5 MTPA of capacity was added across Egypt, Jordan, and Pakistan. Although an FSRU arrived in Ghana during 2016, land-based infrastructure has been the critical path to start-up. Looking forward, several FSRU projects are in advanced stages for Uruguay, Chile, Puerto Rico, and Russia. Turkey's first offshore regasification terminal was able to come online in under one year of construction, demonstrating the speed with which new projects utilizing FSRU technology can be brought online. Although there are eight FSRUs on the order book as of January 2017, very few existing FSRUs were available for charter, leading shipping companies to order new FSRUs or convert existing conventional vessels on a speculative basis.

439 Vessels
LNG fleet, January 2017

Shipping Fleet: The global LNG shipping fleet consisted of 439 vessels as of January 2017, including conventional vessels and ships acting as FSRUs and floating storage units. In 2016, a total of 31 newbuilds (including two FSRUs) were delivered from shipyards, a 7% increase when compared to 2015. Relative to the previous year, this was a much more balanced addition relative to liquefaction capacity (which grew by 35 MTPA). Nevertheless, the accumulation of the tonnage buildout from the previous years is still being worked through, keeping short-term charter rates at historical lows. In 2016, two vessels were retired and sold for scrap.

10% of Supply
Share of LNG in global gas supply in 2015[3]

LNG in the global gas market: Natural gas accounts for roughly a quarter of global energy demand, of which 9.8% is supplied as LNG. Although LNG supply previously grew faster than any other natural gas supply source – averaging 6.2% per annum from 2000 to 2015 – its market share growth has stalled since 2010 as indigenous production and pipeline supply have competed well for growing global gas markets. Despite the lack of market share growth in recent years, the large additions of LNG supply through 2020 mean LNG is poised to resume its expansion.

[2] This 81 MTPA is included in the global regasification capacity total of 793 MTPA quoted above.
[3] Data for pipeline trade and indigenous gas production comes from the BP Statistical Review. Data for 2016 is not yet available.

Exhibit 2

Industrial Energy Consumers of America
The Voice of the Industrial Energy Consumers

1776 K Street, NW, Suite 720 • Washington, D.C. 20006
Telephone (202) 223-1420 • www.ieca-us.org

August 16, 2017

The Honorable Rick Perry
Secretary
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Re: Manufacturers Urge DOE to Place Moratorium on LNG Export Approvals for NFTA Countries – Demand Scenarios Demonstrate that 58-71 Percent of All U.S. Technically Recoverable Natural Gas Resources Could be Consumed by 2050

Dear Secretary Perry:

As large manufacturing consumers of natural gas, natural gas feedstock, and natural gas-fired electricity generation, we remain alarmed at the volume of LNG exports that have been approved for periods of 20-30 years, especially to non-free trade agreement (NFTA) countries. The two cumulative demand scenarios presented below provide absolute justification for placing a moratorium on further NFTA applications by the U.S. Department of Energy (DOE). Scenario II below assumes that LNG exports will rise to currently approved applications in the amount of 54 billion cubic feet per day (Bcf/d) by 2050, only 33 years away. Given this cumulative export and domestic demand scenario, the U.S. would consume 71 percent of all U.S. technically recoverable natural gas resources. We also reaffirm our opposition to shipping LNG to NFTA countries, which is inconsistent with President Trump's fair-trade and "America First" policies.

Importantly, the Obama Administration's "public interest" LNG export studies, which are still being used to justify LNG export approvals to NFTA countries, did not consider the "cumulative" export volume to FTA and NFTA countries and how it could contribute to consumption of vast amounts of U.S. natural resources nor its economic impact.

According to the DOE and the Energy Information Administration (EIA), total LNG export approvals to both free-trade agreement (FTA) countries and NFTA countries now equals 71.2 percent of U.S. 2016 natural gas demand. Approved volumes to NFTA countries alone equals 170 percent of total residential demand. Of greatest concern, is that the Administration has said publicly that it will approve more applications to export to NFTA countries.

We recognize that the DOE is still staffing up to properly manage the many important matters that the department handles. And for this reason, we are providing you with a record of IECA communications regarding LNG exports.

- April 13, 2017: IECA responds to the incorrect claims made by the Center for Liquefied Natural Gas (CLNG) (http://www.ieca-us.com/wp-content/uploads/04.13.17_Letter-to-Secretary-Perry_DOE.pdf)

- May 18, 2017: IECA testifies before the International Trade Administration and makes the point that the Obama Administration's LNG export "public interest" studies were terribly flawed; LNG markets are not free or fair markets; the co-called 100-year supply is a myth; that EIA forecasted Henry Hub prices are estimated to increase by 118 percent by 2025 in large part due to natural gas exports. (http://www.ieca-us.com/wp-content/uploads/05.18.17_Cicio-Testimony-Before-DOC-on-Trade-and-LNG.pdf)

- June 28, 2017: This letter to you provides five public interest policy recommendations; provides justification for prudent common-sense consumer safeguards. (http://www.ieca-us.com/wp-content/uploads/06.28.17_Letter-to-Perry_Ross-on-LNG-Policy-Recommendations.pdf)

- July 11, 2017: WSJ story illustrates how Australia LNG exports resulted in a domestic shortage for consumers, despite having vast natural gas resources. Australia never put in place consumer safeguards. IECA urges DOE to put consumer safeguards in place. (http://www.ieca-us.com/wp-content/uploads/07.11.17_WSJ_Australian-LNG-Story-Press-Release.pdf)

Natural Gas Consumption Scenario I

Scenario I assumes the EIA AEO 2017 cumulative net demand for natural gas, which includes exports of LNG and shipments to Mexico (see Appendix, figure 1), and compares it to the EIA technically recoverable U.S. natural gas resources in the lower 48 (see figure 2). The AEO 2017 forecast includes LNG exports rising to 12.1 Bcf/d by 2035. This scenario illustrates that with only 12.1 Bcf/d of LNG exports, 58 percent of all U.S. technically recoverable natural gas resources are consumed by 2050, only 33 years.

Natural Gas Consumption Scenario II

Scenario II uses the same assumptions as Scenario I, but includes the volume of LNG export applications equal to 54 Bcf/d that the DOE has already approved (see figure 3). Using EIA's annual average forecasted increases in LNG exports from 2016 to 2020 of 1.58 Bcf/d and using this same growth rate for the years beyond 2020 until LNG export volumes reach 54 Bcf/d, 71 percent of U.S. technically recoverable resources are consumed by 2050.

We are aware that just recently the Potential Gas Committee released an updated assessment of U.S. natural gas resources which increased its estimates by 300 Tcf. Even with this non-governmental assessment, paid for the oil and gas industry, it does not blemish the hard realities of Scenarios I or II. The facts are troubling and as stated earlier give justification to halt further approvals for shipments to NFTA countries.

The Natural Gas Act (NGA) Requires That LNG Export Applications For Shipment To NFTA Countries Must Not Be In Conflict With The "Public Interest"

We urge you to review the Obama Administration's DOE studies on the economic impacts of LNG exports that are being used to justify further export application approvals. As referenced earlier, the Obama Administration did not consider the cumulative export volume to FTA and NFTA countries when it did its public interest LNG export studies, as IECA has done so, with its two scenarios. Also, you will find that the Obama Administration studies understate impacts to the manufacturing sector and jobs. And, the so-called net economic benefit is so small that it is within error of the economic model output. Below is a direct quote from the October 29, 2015 report, "The Macroeconomic Impact of Increased U.S. LNG Exports" that considers the economic impacts for LNG export levels to 20 Bcf/d. To date, the DOE has given final approval to 20.6 Bcf/d.

> "As exports increase, the spread between U.S. domestic prices and international prices narrows. In every case, greater LNG exports raise domestic prices and lower prices internationally. The majority of the price movement (in absolute terms) occurs in Asia (page 8)."

The net effect is that LNG exports, specifically to NFTA countries lowers our competitors' costs and increases ours, directly and negatively impacting competitiveness and our ability to justify reshoring.

Producing and Exporting LNG Is Not a Large Job Creator – It Is a Manufacturing Job Destroyer Long-Term

When making a comparison to manufacturing, for example, according to the U.S. Bureau of Labor Statistics, from 2010 to 2016, the entire oil and gas industry created only 21 thousand jobs. During that same time, the manufacturing sector created 820 thousand jobs. Manufacturing can create eight times more jobs using natural gas rather than exporting it.

We look forward to discussing these matters with you.

Sincerely,

Paul N. Cicio
President

cc: Senate Committee on Energy and Natural Resources
House Committee on Energy and Commerce
The Honorable Wilbur Ross, U.S. Department of Commerce
The Honorable Robert Lighthizer, U.S. Trade Representative

APPENDIX

Figure 1: U.S. Natural Gas – EIA AEO 2017 Base Case (Billion Cubic Feet/Day)

Year	Dry Production*	U.S. Consumption	EIA LNG Exports**	Net Exports to Mexico	Net Exports to Canada	Total Consumption
2014	71.0	72.9	-0.1	1.9	-5.2	69.5
2015	74.2	74.8	-0.2	3.0	-5.2	72.4
2016	72.6	75.3	0.2	3.8	-5.8	73.5
2017	76.4	76.3	1.4	3.3	-5.2	75.8
2018	79.7	77.0	2.7	4.4	-4.9	79.2
2019	82.5	76.3	4.9	4.7	-4.1	81.8
2020	84.4	74.8	7.9	4.9	-3.6	84.0
2021	84.9	74.5	8.2	4.9	-3.3	84.3
2022	85.8	74.5	8.5	4.7	-2.7	85.0
2023	87.1	75.1	9.0	4.7	-2.5	86.3
2024	88.8	76.2	9.6	4.9	-2.2	88.5
2025	90.7	77.5	9.9	4.9	-2.2	90.1
2026	92.1	78.6	10.4	4.9	-1.9	92.0
2027	93.2	78.9	10.7	4.9	-1.6	92.9
2028	94.0	79.5	11.0	4.9	-1.6	93.8
2029	95.1	80.3	11.0	4.7	-1.1	94.9
2030	95.6	80.8	11.0	4.7	-1.1	95.4
2031	95.9	80.5	11.2	4.7	-1.1	95.3
2032	96.7	81.4	11.5	4.7	-1.1	96.5
2033	97.3	81.6	11.8	4.7	-0.8	97.3
2034	98.6	82.7	11.8	4.4	-0.8	98.1
2035	100.0	84.1	12.1	4.4	-0.5	100.1
2036	100.5	84.4	12.1	4.4	-0.5	100.4
2037	101.6	85.5	12.1	4.4	-0.5	101.5
2038	102.5	86.3	12.1	4.4	-0.5	102.3
2039	103.0	86.8	12.1	4.4	-0.5	102.8
2040	103.3	87.4	12.1	4.1	-0.5	103.1
2041	104.1	88.2	12.1	4.1	-0.5	103.9
2042	104.7	88.8	12.1	4.1	-0.5	104.5
2043	104.9	89.3	12.1	4.1	-0.5	105.0
2044	105.8	90.1	12.1	4.1	-0.5	105.8
2045	106.6	91.0	12.1	3.8	-0.5	106.4
2046	107.1	91.8	12.1	3.8	-0.5	107.2
2047	107.9	92.6	12.1	3.8	-0.5	108.0
2048	108.5	93.2	12.1	3.8	-0.5	108.6
2049	109.0	93.7	12.1	3.8	-0.5	109.1
2050	110.4	94.8	12.1	3.6	-0.5	110.0

Year	Dry Production*	U.S. Consumption	EIA LNG Exports**	Net Exports to Mexico	Net Exports to Canada	Total Consumption
Total Consumption	3,516.5	3,057.5	356.0	157.8	-66.0	3,505.3

Source: Energy Information Administration (EIA), AEO 2017
*The process of producing consumer-grade natural gas. Natural gas withdrawn from reservoirs is reduced by volumes used at the production (lease) site and by processing losses. Volumes used at the production site include (1) the volume returned to reservoirs in cycling, repressuring of oil reservoirs, and conservation operations; and (2) gas vented and flared. Processing losses include (1) nonhydrocarbon gases (e.g., water vapor, carbon dioxide, helium, hydrogen sulfide, and nitrogen) removed from the gas stream; and (2) gas converted to liquid form, such as lease condensate and plant liquids. Volumes of dry gas withdrawn from gas storage reservoirs are not considered part of production. Dry natural gas production equals marketed production less extraction loss.
**Net LNG exports includes the Sabine Pass, Dominion, Cameron, Freeport, and Cheniere terminals, already approved and under construction.

Figure 2: EIA – Technically Recoverable U.S. Natural Gas Resources (Billion Cubic Feet/Day)

	Proved Reserves	Unproved Reserves	Total Technically Recoverable Resources
Lower 48 (Onshore)	882.7	4,243.6	5,126.3
Lower 48 (Offshore)	23.8	866.3	890.1
TOTAL	**906.5**	**5,109.9**	**6,016.4**

Source: Technically recoverable U.S. dry natural gas resources as of January 1, 2014, Energy Information Administration (EIA) https://www.eia.gov/outlooks/aeo/assumptions/pdf/oilgas.pdf
Note: Data does not include Alaska (onshore and offshore).

Figure 3: U.S. Natural Gas – EIA AEO 2017 Base Case w/ IECA Assumptions (Billion Cubic Feet/Day)

Year	Dry Production*	U.S. Consumption	EIA LNG Exports**	IECA LNG Export Assumptions***	Net Exports to Mexico	Net Exports to Canada	Total Consumption
2014	71.0	72.9	-0.1	0.0	1.9	-5.2	69.5
2015	74.2	74.8	-0.2	0.0	3.0	-5.2	72.4
2016	72.6	75.3	0.2	0.0	3.8	-5.8	73.5
2017	76.4	76.3	1.4	0.0	3.3	-5.2	75.8
2018	79.7	77.0	2.7	0.0	4.4	-4.9	79.2
2019	82.5	76.3	4.9	0.0	4.7	-4.1	81.8
2020	84.4	74.8	7.9	1.6	4.9	-3.6	85.6
2021	84.9	74.5	8.2	3.2	4.9	-3.3	87.5
2022	85.8	74.5	8.5	4.8	4.7	-2.7	89.8
2023	87.1	75.1	9.0	6.4	4.7	-2.5	92.7
2024	88.8	76.2	9.6	8.0	4.9	-2.2	96.5
2025	90.7	77.5	9.9	9.6	4.9	-2.2	99.7

Year	Dry Production*	U.S. Consumption	EIA LNG Exports**	IECA LNG Export Assumptions***	Net Exports to Mexico	Net Exports to Canada	Total Consumption
2026	92.1	78.6	10.4	11.2	4.9	-1.9	103.2
2027	93.2	78.9	10.7	12.8	4.9	-1.6	105.7
2028	94.0	79.5	11.0	14.4	4.9	-1.6	108.2
2029	95.1	80.3	11.0	16.0	4.7	-1.1	110.9
2030	95.6	80.8	11.0	17.6	4.7	-1.1	113.0
2031	95.9	80.5	11.2	19.2	4.7	-1.1	114.5
2032	96.7	81.4	11.5	20.8	4.7	-1.1	117.3
2033	97.3	81.6	11.8	22.4	4.7	-0.8	119.7
2034	98.6	82.7	11.8	24.0	4.4	-0.8	122.1
2035	100.0	84.1	12.1	25.6	4.4	-0.5	125.7
2036	100.5	84.4	12.1	27.2	4.4	-0.5	127.6
2037	101.6	85.5	12.1	28.8	4.4	-0.5	130.3
2038	102.5	86.3	12.1	30.4	4.4	-0.5	132.7
2039	103.0	86.8	12.1	32.0	4.4	-0.5	134.8
2040	103.3	87.4	12.1	33.6	4.1	-0.5	136.7
2041	104.1	88.2	12.1	35.2	4.1	-0.5	139.1
2042	104.7	88.8	12.1	36.8	4.1	-0.5	141.3
2043	104.9	89.3	12.1	38.4	4.1	-0.5	143.4
2044	105.8	90.1	12.1	40.0	4.1	-0.5	145.8
2045	106.6	91.0	12.1	41.6	3.8	-0.5	148.0
2046	107.1	91.8	12.1	41.9	3.8	-0.5	149.1
2047	107.9	92.6	12.1	41.9	3.8	-0.5	149.9
2048	108.5	93.2	12.1	41.9	3.8	-0.5	150.5
2049	109.0	93.7	12.1	41.9	3.8	-0.5	151.0
2050	110.4	94.8	12.1	41.9	3.6	-0.5	151.9
Total Consumption	3,516.5	3,057.5	356.0	771.1	157.8	-66.0	4,276.4

Source: Energy Information Administration (EIA), AEO 2017

*The process of producing consumer-grade natural gas. Natural gas withdrawn from reservoirs is reduced by volumes used at the production (lease) site and by processing losses. Volumes used at the production site include (1) the volume returned to reservoirs in cycling, repressuring of oil reservoirs, and conservation operations; and (2) gas vented and flared. Processing losses include (1) nonhydrocarbon gases (e.g., water vapor, carbon dioxide, helium, hydrogen sulfide, and nitrogen) removed from the gas stream; and (2) gas converted to liquid form, such as lease condensate and plant liquids. Volumes of dry gas withdrawn from gas storage reservoirs are not considered part of production. Dry natural gas production equals marketed production less extraction loss.

**Net LNG exports includes the Sabine Pass, Dominion, Cameron, Freeport, and Cheniere terminals, already approved and under construction.

***Net LNG exports includes already approved to FTA countries in the amount of 33.4 Bcf/d and to NFTA countries in the amount of 20.6 Bcf/d, for a total of 54.0 Bcf/d. Starting in 2020, each year there is an increase at a cumulative rate of 1.58 Bcf/d, until it peaks at 54.0 Bcf/d. 1.58 Bcf/day is equal to the average annual forecasted rate of LNG exports forecasted by the EIA from 2016 to 2020.

Exhibit 3

Industrial Energy Consumers of America
The Voice of the Industrial Energy Consumers

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August 22, 2017

Mr. John T. Lucas
General Counsel (Acting), Deputy General Counsel
U.S. Department of Energy
1000 Independence Ave. SW
Washington DC 20585

Re: Legal Review of LNG Export Applications to NFTA Countries – Natural Gas Act – Public Interest

Dear Mr. Lucas:

On August 16, the Industrial Energy Consumers of America (IECA) sent a letter to Secretary Perry which outlines how the previous Administration failed to properly conduct public interest determinations on LNG application volumes for export to non-free trade agreement (NFTA) countries, as required under the Natural Gas Act (NGA). The Trump Administration continues to approve NFTA applications using the same flawed and illegal public interest studies. We urge you to conduct a legal review of this matter and halt further considerations of LNG export applications to NFTA countries until the legal review is completed.

The NGA is clear that the intent of Congress was to protect consumers. Congress required that LNG exports to NFTA countries must not conflict with the public interest. The U.S. Department of Energy (DOE) has already approved LNG export volumes to NFTA countries equal to 20.6 Bcf/d or 27.3 percent of U.S. 2016 demand and to FTA countries equal to 33.4 Bcf/d or a 44.4 percent of 2016 U.S. demand. It is unfathomable that such LNG export volumes, which create such known and unknown price and reliability risk long-term, could possibly be in the public interest.

These are massive amounts of U.S. natural gas resources that the DOE has committed to foreign nations and their buyers, many of which are state-owned enterprises, for periods of 20-30 years. LNG exports reduce foreign LNG buyer risks and increases risks upon U.S. consumers – who have no alternative for natural gas.

The American public has no idea what the DOE has done to mortgage their natural gas future. Today, the U.S. natural gas market is a “free market” whereby price is determined by domestic supply and demand. If we export too much LNG, prices will eventually rise to global levels. At that point, foreign nations demand for LNG will dictate what price Americans pay. This is certainly not in the interests of the American public.

We look forward to discussing this with you.

Sincerely,

Paul N. Cicio
President

cc: Senate Committee on Energy and Natural Resources
House Committee on Energy and Commerce
The Honorable Neil Chatterjee, FERC
The Honorable Robert F. Powelson, FERC
The Honorable Cheryl A. LaFleur, FERC

The Industrial Energy Consumers of America is a nonpartisan association of leading manufacturing companies with $1.0 trillion in annual sales, over 2,600 facilities nationwide, and with more than 1.7 million employees worldwide. It is an organization created to promote the interests of manufacturing companies through advocacy and collaboration for which the availability, use and cost of energy, power or feedstock play a significant role in their ability to compete in domestic and world markets. IECA membership represents a diverse set of industries including: chemicals, plastics, steel, iron ore, aluminum, paper, food processing, fertilizer, insulation, glass, industrial gases, pharmaceutical, building products, automotive, brewing, independent oil refining, and cement.

Exhibit 4

http://today.oregonstate.edu/archives/2015/feb/study-outlines-threat-ocean-acidification-coastal-communities-us

Study outlines threat of ocean acidification to coastal communities in U.S.

Feb 23, 2015

CORVALLIS, Ore. - Coastal communities in 15 states that depend on the $1 billion shelled mollusk industry (primarily oysters and clams) are at long-term economic risk from the increasing threat of ocean acidification, a new report concludes.

This first nationwide vulnerability analysis, which was funded through the National Science Foundation's National Socio-Environmental Synthesis Center, was published today in the journal Nature Climate Change.

The Pacific Northwest has been the most frequently cited region with vulnerable shellfish populations, the authors say, but the report notes that newly identified areas of risk from acidification range from Maine to the Chesapeake Bay, to the bayous of Louisiana.

"Ocean acidification has already cost the oyster industry in the Pacific Northwest nearly $110 million and jeopardized about 3,200 jobs," said Julie Ekstrom, who was lead author on the study while with the Natural Resources Defense Council. She is now at the University of California at Davis.

George Waldbusser, an Oregon State University marine ecologist and biogeochemist, said the spreading impact of ocean acidification is due primarily to increases in greenhouse gases.

"This clearly illustrates the vulnerability of communities dependent on shellfish to ocean acidification," said Waldbusser, a researcher in OSU's College of Earth, Ocean, and Atmospheric Sciences and co-author on the paper. "We are still finding ways to increase the adaptive capacity of these communities and industries to cope, and refining our understanding of various species' specific responses to acidification.

"Ultimately, however, without curbing carbon emissions, we will eventually run out of tools to address the short-term and we will be stuck with a much larger long-term problem," Waldbusser added.

The analysis identified several "hot zones" facing a number of risk factors. These include:

- The Pacific Northwest: Oregon and Washington coasts and estuaries have a "potent combination" of risk factors, including cold waters, upwelling currents that bring corrosive waters closer to the surface, corrosive rivers, and nutrient pollution from land runoff;

- New England: The product ports of Maine and southern New Hampshire feature poorly buffered rivers running into cold New England waters, which are especially enriched with acidifying carbon dioxide;

- Mid-Atlantic: East coast estuaries including Narragansett Bay, Chesapeake Bay, and Long Island Sound have an abundance of nitrogen pollution, which exacerbates ocean acidification in waters that are shellfish-rich;

- Gulf of Mexico: Terrebonne and Plaquemines Parishes of Louisiana, and other communities in the region, have shellfish economies based almost solely on oysters, giving this region fewer options for alternative - and possibly more resilient - mollusk fisheries.

The project team has also developed an interactive map to explore the vulnerability factors regionally.

One concern, the authors say, is that many of the most economically dependent regions - including Massachusetts, New Jersey, Virginia and Louisiana - are least prepared to respond, with minimal research and monitoring assets for ocean acidification.

The Pacific Northwest, on the other hand, has a robust research effort led by Oregon State University researchers, who already have helped oyster hatcheries reboundfrom near-disastrous larval die-offs over the past decade. The university recently announced plans to launch a Marine Studies Initiative that would help address complex, multidisciplinary problems such as ocean acidification.

"The power of this project is the collaboration of natural and social scientists focused on a problem that has and will continue to impact industries dependent on the sea," Waldbusser said.

Waldbusser recently led a study that documented how larval oysters are sensitive to a change in the "saturation state" of ocean water - which ultimately is triggered by an increase in carbon dioxide. The inability of ecosystems to provide enough alkalinity to buffer the increase in CO_2 is what kills young oysters in the environment.

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Exhibit 5

Vulnerability and adaptation of US shellfisheries to ocean acidification

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Vulnerability and adaptation of US shellfisheries to ocean acidification

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Ocean acidification is a global, long-term problem whose ultimate solution requires carbon dioxide reduction at a scope and scale that will take decades to accomplish successfully. Until that is achieved, feasible and locally relevant adaptation and mitigation measures are needed. To help to prioritize societal responses to ocean acidification, we present a spatially explicit, multidisciplinary vulnerability analysis of coastal human communities in the United States. We focus our analysis on shelled mollusc harvests, which are likely to be harmed by ocean acidification. Our results highlight US regions most vulnerable to ocean acidification (and why), important knowledge and information gaps, and opportunities to adapt through local actions. The research illustrates the benefits of integrating natural and social sciences to identify actions and other opportunities while policy, stakeholders and scientists are still in relatively early stages of developing research plans and responses to ocean acidification.

The ocean has absorbed about 25% of anthropogenic atmospheric CO_2 emissions, progressively increasing dissolved CO_2, and lowering seawater pH and carbonate ion levels[1]. On top of this progressive global change in oceanic carbon conditions, local factors such as eutrophication[2,3], upwelling of CO_2-enriched waters[4] and river discharge[5] temporarily increase anthropogenic ocean acidification (OA)[6] in coastal waters[7–9]. Ocean acidification could primarily affect human communities by changing marine resource availability[1]. Studies have shown that, in general, shelled molluscs are particularly sensitive to these changes in marine chemistry[10–12]. Shelled molluscs comprise some of the most lucrative and sustainable fisheries in the United States[13]. Ocean acidification has already cost the oyster industry in the US Pacific Northwest nearly $110 million, and directly or indirectly jeopardized about 3,200 jobs[13]. The emergence of real, economically measurable human impacts from OA has sparked a search for regional responses that can be implemented immediately, while we work towards the ultimate global solution: a reduction of atmospheric CO_2 emissions. Yet there is little understanding about which locations and people will be impacted by OA, to what degree, and why, and what can be done to reduce the risks.

Here, we present the first local-level vulnerability assessment for ocean acidification for an entire nation, adapting a well-established framework and focusing on shelled mollusc harvests in the United States; for other evaluations of OA social vulnerability, see refs 14–16. We explored three key dimensions—exposure, sensitivity and adaptive capacity (Fig. 1, Supplementary Fig. S1)—to assess the spatial distribution of vulnerable people and places to OA. The underlying assumption guiding this assessment is that addressing existing vulnerability can reduce future vulnerability to OA, sometimes called 'human-security vulnerability'[15].

Exposure of marine ecosystems addresses acidification driven by global atmospheric CO_2 and amplified by local factors in coastal waters. We divided the coastal waters around the United States into existing National Estuary Research Reserve System bioregions[17] (Supplementary Fig. S7), and for each bioregion, examined: (1) projected changes to ocean chemistry based on a reduction in aragonite saturation state (Ω_{Ar}) (Supplementary Fig. S2), and (2) the prevalence of key local amplifiers of OA, including upwelling, eutrophication and input of river water with low-aragonite saturation state [**AU: OK?**], for each bioregion (Supplementary Figs S4–S6). Aragonite saturation state (Ω_{Ar}) is a measure of the thermodynamic stability of this mineral form of calcium carbonate that is used by bivalve larvae and other molluscs, which is also commonly used to track OA[1]. Declining Ω_{Ar} makes it more difficult and energetically costly for larval bivalves to build shells even before Ω_{Ar} becomes corrosive [**AU: is it Ω_{Ar} that becomes corrosive, or should this be OA?**], and Ω_{Ar} seems to be the important variable for the most sensitive early stage of bivalve larvae[18]. We evaluated relative exposure to anthropogenic OA as the time [**AU: i.e. 'time until', or 'the**

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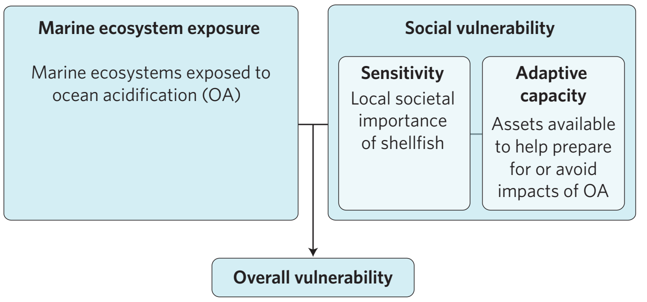

Figure 1 | Conceptual framework structuring the analysis of vulnerability to ocean acidification. Vulnerability analyses can focus on three key dimensions (exposure, sensitivity and adaptive capacity): (1) the extent and degree to which assets are exposed to the hazard of concern; (2) the sensitivity of people to the exposure; and (3) the adaptive capacity of people to prepare for and mitigate the exposure's impacts. These three dimensions together provide a relative view of a place's overall vulnerability. Adapted conceptual model components from refs 16,52–55.

extent of time for which'?] mean annual surface seawater exceeds an empirically informed absolute Ω_{Ar} threshold for several species of bivalve larvae. This indicator for disruption to the biological processes of calcification and development in larval molluscs was favoured over alternatives (for example time until the historic range of Ω_{Ar} is exceeded) because the biological mechanism was clear[19] and empirical evidence exists[20]. For comparison purposes, the Supplementary Information includes the time until the historic range of Ω_{Ar} is exceeded (Supplementary Fig. S3), but below we document the outcomes based on the Ω_{Ar} threshold projections and local amplifiers of OA.

Sensitivity of social systems was evaluated at the scale of 'clusters of coastal counties' around the United States, using three indicators of community dependence on shellfish, adapted from the National Marine Fisheries Service's fishing community vulnerability and resilience index[21]: (1) the 10-year median landed value of shellfish (including both wild and aquaculture harvests); (2) the 10-year median proportional contribution of shellfish to total value of commercial landings; and (3) the 5-year median number of licences (representing jobs) supported by shelled mollusc fishing (Supplementary Information). Sensitivity indicators were re-scaled and combined into a single index (Supplementary Information and Supplementary Fig. S8).

Adaptive capacity of social systems to cope with and adapt to OA is represented by three classes of indicators: status of state government climate and OA policies, local employment alternatives and availability of science. We examined a total of six indicators representing adaptive capacity that are derived largely from the broader economic and policy landscape, yet are directly relevant for dealing with the threat of OA (Supplementary Fig. S9). This is a deliberate departure from studies conducted at broader and finer geographic scales that use general demographic indicators (see Supplementary Information). We assessed 'potential government support for adaptation' through measures of: (1) the status of state legislative action on OA and (2) the status of state climate adaptation planning. These indicators reflect social organization and assets at the state jurisdictional level that could be used by communities to adapt to, cope with, or avoid the impacts of lost shellfish harvests. We examined aspects of employment alternatives through: (3) the diversity of shelled mollusc harvests, suggesting potential alternative shellfish that could be harvested and (4) the diversity of non-shellfish-related employment industries. These reflect the likelihood of job alternatives for shellfish harvesters and those in the aquaculture industry. Finally, we captured 'access to and availability of science' through (5) a score for marine laboratories developed to take into account the high local influence that such laboratories can have as well as the potential contribution beyond their immediate vicinity. For each county cluster, a metric based on the number of university marine laboratories (on-campus and satellite laboratories) in that county cluster was averaged with a metric based on the total number of university marine laboratories in that state (see Supplementary Information for more information) and (6) Sea Grant state budgets normalized by shoreline length. These indicators represent the availability of local scientific capacity, the potential for troubleshooting assistance, and the possibility of access to a range of tools and data products, such as available early warning information. We attributed each county cluster (as used in Sensitivity) to each variable score of the six indicators. We then combined into a single index by averaging re-scaled (0–1) overall component scores for sensitivity and adaptive capacity (Supplementary Information Fig. S9). Coincidence of high marine ecosystem exposure to OA with high sensitivity and low adaptive capacity of social systems reveals the areas at highest overall vulnerability to OA.

Places vulnerable to ocean acidification

Our results show that 16 out of 23 bioregions around the United States are exposed to rapid OA (reaching Ω_{Ar} 1.5 by 2050) or at least one amplifier (Fig. 2; Supplementary Table S1); 10 regions are exposed to two or more threats of acidification (note that Alaska and Hawaii are missing local amplifier data; Fig. 2). The marine ecosystems and shelled molluscs around the Pacific Northwest and Southern Alaska are expected to be exposed soonest to rising global OA, followed by the north-central West Coast and the Gulf of Maine in the northeast United States. Communities highly reliant on shelled molluscs in these bioregions are at risk from OA either now or in the coming decades. In addition, pockets of marine ecosystems along the East and Gulf Coasts will experience acidification earlier than global projections indicate, owing to the presence of local amplifiers such as coastal eutrophication, upwelling and discharge of low-Ω_{Ar} river water (see Supplementary Figs S4–S6, Supplementary Table S1).The inclusion of local amplifiers reveals more coastline segments around the United States that are exposed to acidification risk than when basing exposure solely on global models.

Combining sensitivity and adaptive capacity reveals that the most socially vulnerable communities are spread along the US East Coast and Gulf of Mexico (Fig. 2), yet the sources of high social vulnerability are very different between these two regions (see Supplementary Information for breakdown separated by sensitivity and adaptive capacity, Figs S8 and S9). Specifically, the East Coast is dominated by high levels of sensitivity, or economic dependence, from strong use of shellfish resources. For example, southern Massachusetts measures as having the highest sensitivity. This county cluster ranks in the top four for all three sensitivity indicators (Supplementary Fig. S8), meaning that this area has the highest mollusc harvest revenues of any coastal area in the United States, second highest number of licences and fourth highest proportion of seafood revenues coming from molluscs. In contrast, the Gulf of Mexico region is socially vulnerable from low adaptive capacity, owing to social factors such as low political engagement in OA and climate change, low diversity of shellfish fishery harvest and relatively low science accessibility (Supplementary Fig. S9).

Importantly, our visually combined overall vulnerability analysis reveals that a number of socially vulnerable communities lie adjacent to water bodies that are exposed to a high rate of OA or at least one local amplifier, indicating that these places could be at high overall vulnerability to OA (Fig. 2). The areas that are exposed to OA (including local amplifiers) and high and medium–high social vulnerability coincide include southern Massachusetts, Rhode Island, Connecticut, New Jersey and portions around the

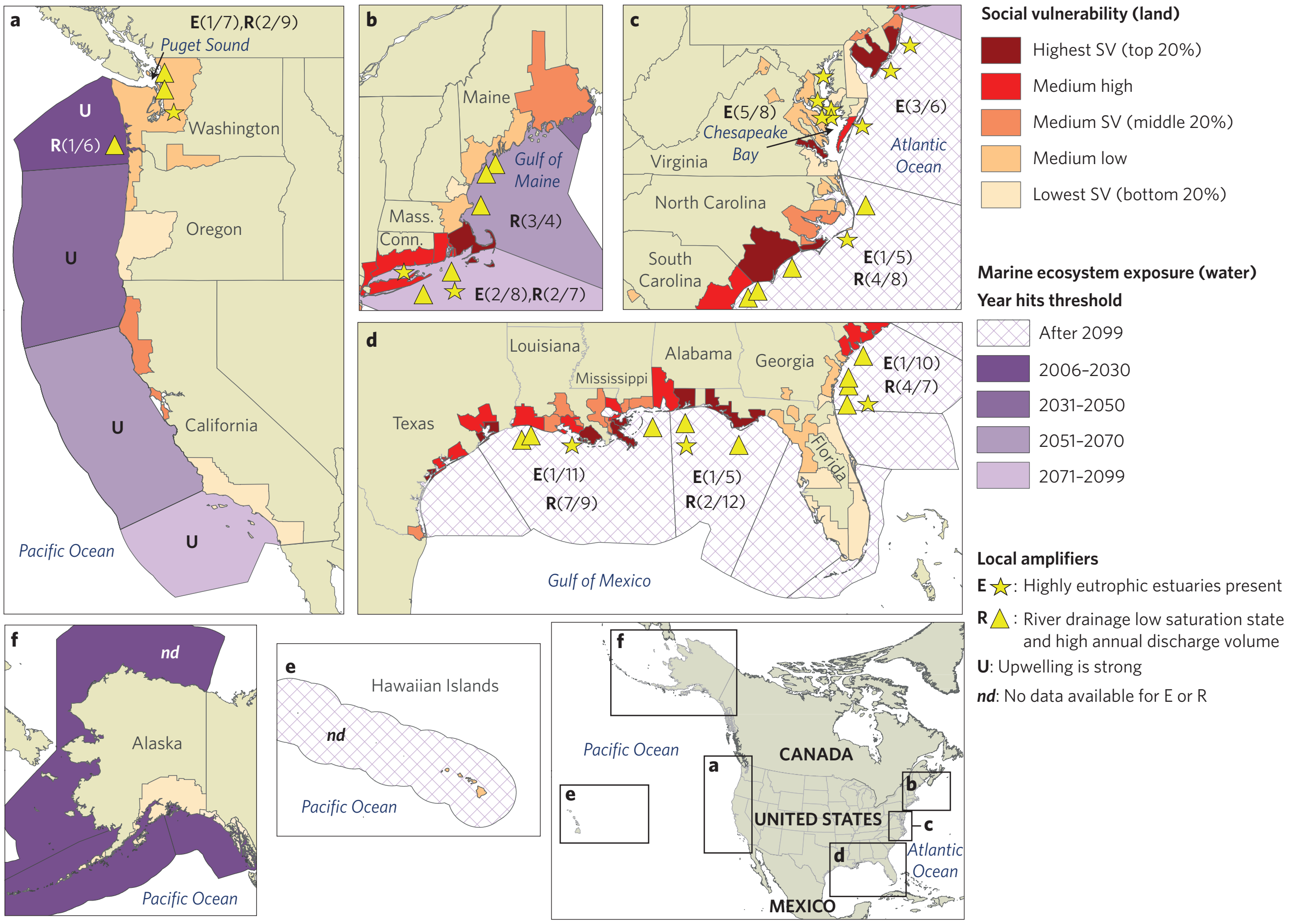

Figure 2 | Overall vulnerability of places to ocean acidification. Scores of relative social vulnerability are shown on land (by coastal county cluster) and the type and degree of severity of OA and local amplifiers to which coastal marine bioregions are exposed, mapped by ocean bioregion: (a) contiguous US West Coast; (b) Northeast; (c) Chesapeake Bay; (d) Gulf of Mexico, and Florida and Georgia's coast; (e) Hawaii Islands; and (f) Alaska. Social vulnerability (red tones) is represented with darker colours where it is relatively high. Exposure (purple tones) is indicated by the year at which sublethal thresholds for bivalve larvae are predicted to be reached, based on climate model projections using the RCP8.5 CO_2 emission scenario[27]. Exposure to this global OA pressure is higher in regions reaching this threshold sooner. Additionally, the presence and degree of exposure to local amplifiers of OA are indicated for each bioregion: E(x/y) marks bioregions [**AU: OK?**] in which highly eutrophic estuaries are documented, x is the number of estuaries scored as high, and y is the total number evaluated in each bioregion (source: ref. 56), locations of highly eutrophic estuaries are marked with a star; R(x/y) marks bioregions in which **sampled river water draining into bioregion scored** [**AU: this description is not clear grammatically: should it be 'bioregions in which... water was scored', or is something missing here? Also, does 'scoring in the top quintile' here mean top quintile of discharge volume only? Please clarify phrasing**] based on very low saturation state and high annual discharge volume (top quintile, calculated by authors from US Geological Survey[57]), x is the number of rivers scoring in the top quintile of those evaluated, and y is the total number evaluated in this study. Approximate locations of river outflows of those rivers scoring in the top quintile are marked with a delta [**AU: a yellow triangle?**]; and U marks bioregions where upwelling is very strong in at least part of the bioregion (source: ref. 58).

Chesapeake Bay, the Carolinas, and areas across the Gulf of Mexico (Fig. 2b–d). Interestingly, global ocean models that project the advance of OA, primarily as a result of atmospheric CO_2, do not reveal these areas as exposed to global OA until after 2099, based on our study's Ω_{Ar} threshold (Table 1). The marine ecosystem exposure in the areas located along the Atlantic coast and the Gulf of Mexico is from low-Ω_{Ar} conditions caused primarily by the addition of river water and eutrophication, local factors that have only more recently been considered major amplifiers of nearshore acidification[6,7]. These coastal processes are likely to tip coastal oceans past organism thresholds as atmospheric CO_2 uptake continues in the future (see ref. 22). Although the Pacific Northwest, northern California and Maine exhibit only medium and medium–low social vulnerability (Fig. 2a,b), these areas are particularly economically sensitive and lie adjacent to marine ecosystems highly exposed to global OA[23,24] (sensitivity, Supplementary Fig. S8). This profile of relatively high dependency and high exposure in these three regions has already activated significant research and local action/engagement among local scientists, government and shellfish growers (see for example refs 25,26). This engagement has driven up adaptive capacity (based on our study's indicators) in these areas, which reduces their social vulnerability relative to other regions across the United States. In comparison, the lower level of OA-related action in other regions such as the Gulf of Mexico (Fig. 2d), Massachusetts (Fig. 2b) and Mid-Atlantic (Figs 2c,d) with high overall vulnerability profiles might be partly because their marine ecosystem exposure is dominated by the presence of local OA amplifiers rather than global OA (Supplementary Fig. S2, Supplementary Table S1). At the same time, some of these areas (for example Maryland) do have strong advocates for addressing water quality which could provide an opportunity to address locally driven acidification as awareness of the issue grows.

[AU: Please indicate where Table 2 should be cited in the text.]

Table 1 | Indicators of drivers and amplifiers of ocean acidification, and the criterion for each used in this study.

Factors causing and amplifying OA (reducing Ω_{Ar})	Indicator	Scoring scale	Criterion for ranking the risk factor as 'high'
Rising atmospheric CO_2 reduces Ω_{Ar} causing chronic stress to shelled mollusc larvae	Projected year that surface water will reach $1.5\Omega_{Ar}$ (ref. 27)	Continuous scale from current year to 2099	$1.5\Omega_{Ar}$ threshold reached by 2050
Eutrophication increases pCO_2 locally via respiration, leading to reduced Ω_{Ar}	Degree of eutrophication[56]	Eutrophication scored on a five-point scale: low to high	Presence of a high-scoring eutrophic estuary in bioregion
River water can reduce Ω_{Ar} locally in coastal waters	Combined metric of river's aragonite saturation state and annual discharge volume	Rivers scored on a five-point scale: low to high	Presence of high scoring river (for low aragonite saturation and high discharge volume) in bioregion
Significant seasonal upwelling delivers water rich in CO_2 to shallow waters, leading to reduced Ω_{Ar}	Degree of upwelling[58]	Coastal zones scored on a five-point scale: low to high	Presence of high upwelling zone in bioregion

Table 2 | Indicators representing 'sensitivity' (people's dependency) on organisms expected to be affected by ocean acidification (in this study, shelled molluscs).

Indicator or measure	Source	Raw format	Processing for subindex
Landed value (median of 10 years)	Regional fisheries databases (ACCSP, GulfBase, PacFIN), and States of Alaska and Hawaii	US dollars, annual	Calculated median for years 2003–2012 Winsorized the top 10%
Percentage of shellfish by value **[AU: i.e. as percentage of all fish caught?]** (median of 10 years)		For each year: shelled molluscs value/total commercial landed value	Divided landed value of shellfish by landed value of all fish Winsorized the top 10%
Number of licences as proxy for jobs (median over 5 years)		Number of commercial licences, annual	Winsorized the top 10%

All indicators are in units of county clusters.

Robustness of analysis

To examine the robustness of these spatial patterns of vulnerability, we varied the index aggregation methodology and the selection of indicators. To test the difference in index aggregation methods for social vulnerability, we compared the output of adding and multiplying sensitivity and adaptive capacity indices and found little difference; the same set of county clusters made up the top 10 most socially vulnerable places using either aggregation method.

To explore the effect of indicator selection on adaptive capacity (and thus social vulnerability), we compared a set of commonly used generic indicators for adaptive capacity relating to income, poverty, education and age with the set of threat-specific indicators developed for this study (see Table 3 and Supplementary Figs S10 and S11). Using the generic capacity measures to calculate social vulnerability, we found that six of the same county clusters measured within the top 10 highest socially vulnerability places in the United States as those found using the threat-specific indicators (see Supplementary Information for analysis and maps). This is considerable overlap given that the two sets of variables indicate entirely different notions of adaptive capacity. Because the sensitivity indicators were developed and vetted by fisheries social science researchers[21] and alternative potentially appropriate data were not available nationwide, we did not have a useful comparison for this element from which to draw.

To explore the criterion for Ω_{Ar}, we examined one alternative for disruption of biological processes with respect to rising atmospheric CO_2: the time until average surface waters move outside the present range of Ω_{Ar} (that is, exceeding a historic envelope)[27]. The map generated by this 'historic envelope' approach shows that southern areas experience potential OA exposure earlier, which is nearly an inverse pattern to our chosen criterion of a chemical threshold when calcification and development of larval molluscs may decrease (Supplementary Fig. S3). This difference in patterns is because natural variability is much smaller in southern regions, although evidence of greater sensitivity in populations of bivalves that live in tropical and subtropical waters is lacking. This discrepancy underscores the need for targeted research integrating a physiological, ecological and evolutionary perspective on the potential and limitations of strong local biological adaptation to different carbonate regimes for commercially valuable shelled mollusc populations.

Overall, we found that variable selection has stronger effects than aggregation methods, which provides high confidence in our aggregation methods for social vulnerability. The differences found in variable selection identify research needs relating to what factors underlie vulnerability on the ground that are relevant to OA; this conversation has only just begun.

Opportunities to reduce vulnerability to ocean acidification

Social–environmental syntheses, including vulnerability analyses, can help to identify opportunities for actionable solutions to address the potential impacts of ocean acidification. Our analysis reveals where and why the overall vulnerability from OA varies among the many coastal areas of the United States, and thus identifies opportunities to reduce harm.

One way to tackle OA is by reducing marine ecosystem exposure to it. Several portions of the east coast are highly exposed to OA from high levels of eutrophication (Fig. 2b–d). In addition to releasing extra dissolved CO_2 and enhancing acidification, eutrophication can also decrease seawater's ability to buffer further acidification[3]. People in these regions are uniquely positioned to reduce exposure to OA through regional actions by curtailing eutrophication (as compared, for example, with regions exposed to upwelling). Although a significant challenge, reducing nutrient loading to the coastal zone in these areas could provide multiple benefits, making it a no-regrets option. Reducing eutrophication can decrease hypoxia and harmful algal blooms, in addition to reducing risk from fossil-fuel-derived OA at the local and regional level. Policy

Table 3 | Threat-specific indicators used to assess capacity of fishing communities to deal with impacts of ocean acidification.

Group	Indicator	Source	Raw format	Processing for subindex
Access to scientific knowledge	Budget of Sea Grant programmes	National Sea Grant	State-level total funds of budget (state and federal contributions combined, 2013)	• Re-scaled (0–1) • Attributed normalized scores to each county cluster
	Number of university marine laboratories	Direct count from registries and Internet	Latitude/longitude location of laboratories	• Combined score of laboratories per state/shoreline length and labs per county cluster
Employment alternatives	Shelled mollusc diversity	Regional fisheries databases (ACCSP, GulfBase, PacFIN), and States of Alaska and Hawaii	Ratio of landing revenues for each taxon by county cluster	• Calculated Shannon Weiner Diversity Index
	Economic diversity	ACS Census	Proportion of county population employed in each industry	• Calculated Shannon Weiner Diversity Index for county clusters
Political action	Legislative action for OA	Keyword searches on legislature websites and follow-up calls	Established five-point scale for state's legislative progress on OA	• Re-scaled 0–1 • Attributed score to county clusters
	Climate adaptation planning	Georgetown Law School Climate programme website	Status of climate adaptation plan for state	• Re-scaled 0–1 • Attributed score to country clusters

See Supplementary Information for discussion and presentation of alternative indicators and measures.

instruments to reduce eutrophication exist in the United States[28] and can be leveraged to facilitate efforts to reduce OA[8].

Another important way to combat the effects of OA will be by reducing social vulnerability. In regions where high sensitivity (one component of social vulnerability) arises from the structure of the fishing industry, an entirely different approach to adaptation may be more appropriate than those geared to reduce marine ecosystem exposure. For example, where fishery harvest portfolios are dominated by a single species, such as in the Gulf of Mexico where mollusc production is limited to the eastern oyster (*Crassostrea virginica*), diversification of the species harvested might be a beneficial strategy.

A further way to reduce social vulnerability may be by increasing adaptive capacity of people and regions. Access and availability to science already has helped shellfish aquaculturists in the Pacific Northwest to identify and avoid some of the consequences of OA[20]. Working with local scientists, hatcheries have implemented several strategies to adapt and mitigate OA effects on bivalve seed production. Through local industry–research partnerships in the Pacific Northwest, implementation of real-time monitoring of saturation state, chemical buffering of water, changes in timing of seasonal seed production and use of selectively bred lines of oyster broodstock, this collaboration has prevented collapse of the regional oyster industry.

In every case, when developing a broader array of adaptation strategies, it is critical to work directly with the coastal communities in each region so they can develop context-appropriate and feasible adaptation options. Targeted projects to develop local adaptation plans may even require developing further regionally relevant indicators of adaptive capacity and community resilience that this nationwide study does not capture. In fact, zooming in to assess particular regions at a higher resolution would enable regional stakeholders to provide input into a possible different set of variables that defines vulnerability in their particular region based on values and social or economic context.

Barriers to and path forward for addressing OA

This study offers the first nationwide vulnerability assessment of the spatial distribution of local vulnerability from OA focusing on a valuable marine resource. But it is just a first step to understanding where and how humans and marine resources are at highest risk to OA and its local amplifiers. Another key finding of this assessment is that significant gaps in the scientific understanding of coastal ocean carbonate dynamics, organismal response and people's dependence on impacted organisms limit our ability to develop a full suite of options to prepare for, mitigate and adapt to the threats posed by OA, and these can be considered in a structured way using the framework (Fig. 3). The types of gaps identified—as commonly classified in information science and other disciplines[29,30]—range from data inaccessibility to knowledge deficiencies.

Marine ecosystem exposure. Key gaps remain in understanding how global and local processes interact to drive nearshore OA, and how this will affect marine organisms and ecological systems. Recent studies suggest that the biogeochemical interaction between global OA and local amplifiers is additive[3,22,31]; however, most ocean models used to project future OA cannot adequately resolve these processes, which are also increasingly affected by human activity[7,32]. Even though direct measurements incorporate an ever-growing global network of monitoring instruments, they are often located offshore and remain too sparse in space and time to resolve the dynamics of seawater chemistry near shore, where most shellfish live. Historically, OA monitoring has focused on offshore regions, where long-term, high-accuracy and precise measurements enabled detection and attribution of the rising atmospheric CO_2 acidification signal. But many commercially and nutritionally important organisms live in the coastal zone where they experience the combined effects of multiple processes that alter the carbonate chemistry[7]. This results in greatly variable 'carbonate weather' for a given location[33]. Characterizing this variation, including modelling how rising atmospheric CO_2 will increase the frequency, duration and severity of extreme events **[AU:OK?]**, would provide a fuller picture of how OA is unfolding within the dynamic coastal waters.

To improve our understanding of which marine ecosystems and organisms are most susceptible to ocean acidification, additional information on the Ω_{Ar} thresholds below which reproduction and survival are disrupted is needed. In the US context, the

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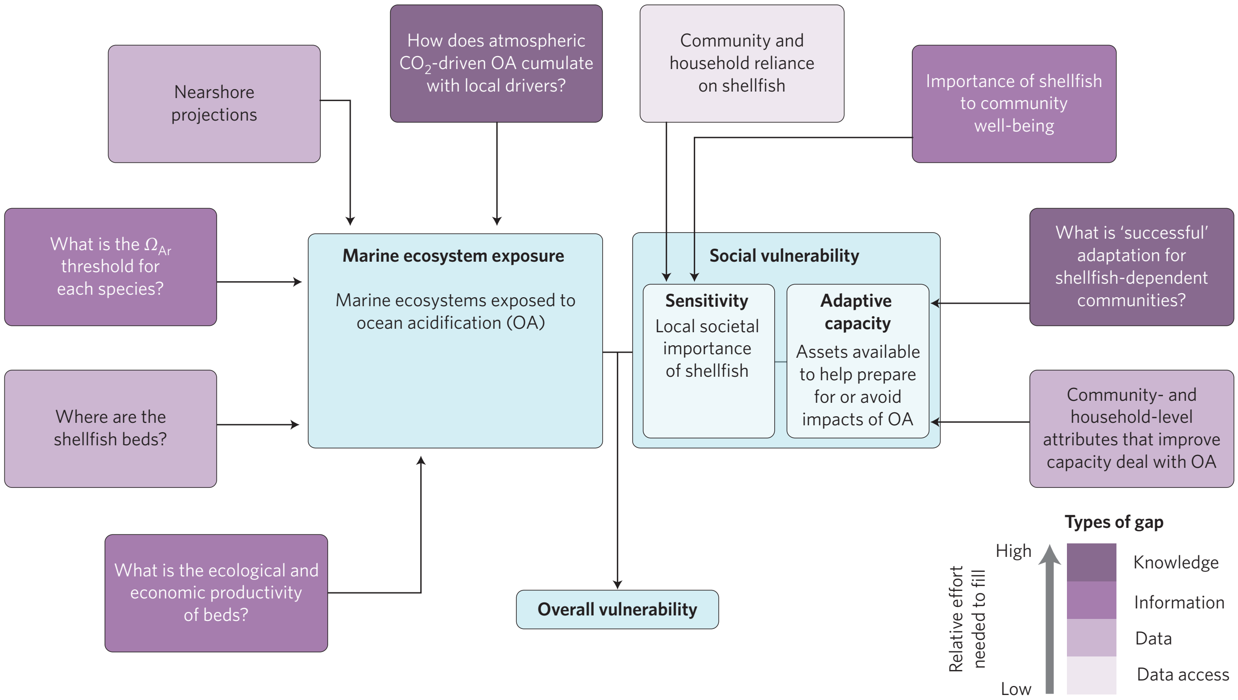

Figure 3 | Sample of gaps in knowledge related to OA vulnerability, information and data organized around components of the framework. Different types of gaps are classified by the level of effort that is required to fill them (gaining knowledge is the most challenging, whereas data access tends to be the most straightforward).

concentration of value in a limited number of shellfish species means that the identification of biologically susceptible and resistant species and populations is both prudent and feasible. Based on total landed value from 2003 to 2012, approximately 95% of shelled-mollusc revenues in the United States come from only 10 species (and 80% from five). These species include sea scallop (52.9%), eastern oyster (11.3%), Pacific geoduck (5.8%), Pacific oyster (5.2%) and six species of clam (that range from 5% to 2.6% of total value)[34]. There is some evidence of local biological adaptation of other marine taxa to varying carbonate chemistry regimes[35–37]. This potential genetic variation, if present, could be documented to aid in the development of resistant strains of cultured or other organisms.

Social vulnerability. Our study also revealed large gaps in information about mollusc-dependent communities to inform measures of social vulnerability. We do not have high-resolution nationwide data on the full cultural and societal significance of shelled molluscs. Even data on the contributions of shellfish to human nutrition, shoreline protection, and water filtration were inadequate nationwide. Incorporation of these other ecosystem services provided by molluscs could alter the social vulnerability landscape. For the commercial fisheries data that we did obtain, confidentiality constraints forced us to aggregate our analysis into county clusters, preventing county-specific or port-level analyses of social vulnerability that might have revealed more spatial heterogeneity. We also lack social science data that describe use at species-, human community-, port- or household levels. We lack data on the value chain that links threatened organisms to harvesters, processors and end-users. Finally, empirically tested adaptive capacity measures could contribute to a more rigorous evaluation of social vulnerability. This includes data on scientific spending and infrastructure directly relevant to end-users, as well as social and demographic data that are reflective of end-users (for this study, fishing and aquaculture communities) and not the general population (for example generic indicators quantifying education and income).

Beyond helping in prioritizing and developing adaptation strategies, social science is also useful to inform and guide planning for social adaptation and mitigation. As with climate change adaptation, preparing for and adapting to the impacts of OA is a social process[1,38,39]. Implementation does not occur automatically once strategies are developed, but instead must often overcome a suite of institutional (including legal), political, psychological and other types of barriers[40]. As learned from climate change initiatives, the 'softer side' of adaptation (such as coordination among stakeholders, industry and scientists) is the first step towards preparing for a threat like OA[41]. Despite its fundamental importance, this type of effort is often overlooked and remains underfunded. Social science can also help practitioners even in early stages of adaptation figure out how to engage public and policy-makers effectively in OA issues[42–44]. Farther along in adaptation processes, social science can inform the development of strategies by accounting for social values[45,46] and existing property rights in use and norms[47,48] and even helping to work out what type of information is salient for and trusted by decision-makers[49,50]. Although important for reducing its risks, social science relevant for understanding OA has been minimal thus far. A budget assessment conducted by the Interagency Working Group on Ocean Acidification reported that federal research in fiscal year 2011 allocated $270,000 of Federal funds for social science research related to OA, which represents 0.9% of the entire OA spending for that year's budget[51].

Conclusions

As with other global environmental changes, acidification of the oceans is a complex and seemingly overwhelming problem. Here we have focused only on OA (and nearshore amplifiers) as the threat to coastal species. Although other stressors also threaten coastal ecosystems, our single-threat assessment allows us to tease out where OA in isolation could hit people and organisms the hardest, which can inform research agendas and decision-making geared specifically to address OA. A vulnerability framework helps to structure our thinking about the ways in which ocean acidification will affect ecosystems and people. The framework also helps to identify and organize the opportunities and challenges in dealing with these problems. But this study is the beginning; adaptation to OA and other global environmental change is an iterative process that requires both top-down and bottom-up processes. Our analysis of OA as it relates to [**AU: OK**?] US shelled mollusc fisheries makes clear just how much the pieces of the OA puzzle vary around the country. Marine ecosystem exposure, economic dependence and social capacity to adapt create a mosaic of vulnerability nationwide. An even more diverse set of strategies may be needed to help shellfish-dependent coastal communities adapt to OA. Rather than create and apply a nationwide solution, decision-makers and other stakeholders will have to work with fishing and aquaculture communities to develop tailored locally and socially relevant strategies. Meaningful adaptation to OA will require planning and action at all levels, including regional and local levels, which can be supported with resources, monitoring, coordination and guidance at the national level.

Over the past decade, scientists' understanding of ocean acidification has matured, awareness has risen and political action has grown. The next step is to develop targeted efforts tailored to reducing social and ecological vulnerabilities and addressing local needs. Tools like this framework can offer a holistic view of the problem and shed light on where in the social–ecological system to begin searching for locally appropriate solutions.

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Author contributions
All authors provided input into data analysis and research design, and participated in at least one SESYNC workshop; J.A.E. led the drafting of the text with main contributions from L.S., S.R.C., L.H.P., G.G.W. and J.E.C.; R.v.H. contributed projections of ocean acidification; J.A.E., L.S., S.R.C., J.R. and C.D. collected the data; J.A.E. carried out data analysis and mapping.

Additional information
Supplementary information is available in the online version of the paper. Reprints and permissions information is available online at www.nature.com/reprints. Correspondence should be addressed to J.A.E.

Competing financial interests
The authors declare no competing financial interests. [**AUTHORS: OK?]**

EXHIBIT 6

https://newfoodeconomy.org/ocean-acidification-oysters-dungeness-crabs/

The ocean is changing faster than it has in the last 66 million years. Now, Oregon oysters are being farmed in Hawaii. That fix won't work forever.

November 28th, 2017
by H. Claire Brown

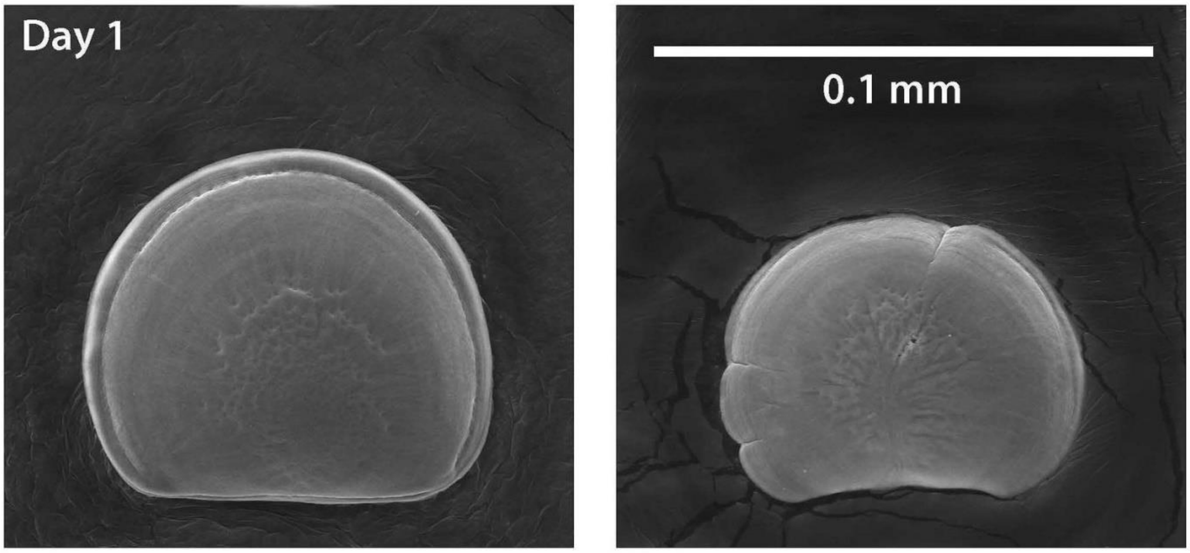
A little more than ten years ago, a mysterious epidemic wiped out baby oyster populations. It started in 2006, when Whiskey Creek shellfish hatchery in Oregon lost 80 percent of its cultured larvae. Around the same time, 200 miles north in Washington, Taylor Shellfish saw similarly high mortality rates. And oysters in the wild weren't faring much better: Oystermen who usually sourced larvae from Washington's Willapa Bay, one of the largest natural oyster-producing estuaries in the country, weren't finding enough stock to seed their beds.

It wasn't long before the epidemic migrated to the East Coast. In the Gulf of Maine, hatchery owner Bill Mook began to notice larval die-offs and slowed growth rates following big storms that pumped fresh water into his hatchery starting in 2009. Sometimes, the surviving organisms were severely deformed. No one knew exactly what had gone wrong.

> After two years of massive losses, scientists discovered what was really wrong.

Suspecting bacterial infection or a problem with the feed, Whiskey Creek and Taylor Shellfish invested in machines that kill *vibrio tubiashii,* a bacteria that is a common culprit in oyster larvae die-offs. Survival rates didn't improve.

But after two years of massive losses and no answers, scientists testing the waters discovered what was really wrong: the ocean water flowing into the hatcheries had changed, and the oysters weren't able to build their shells. Without shells, they couldn't survive.



Flickr / Oregon State University

Oyster larvae in normal conditions (left) versus oyster larvae in acidified conditions (right)

Larval oysters experience a crucial phase in their life cycle where they morph from a form not unlike free-floating dust particles into lentil-sized bivalves with the beginnings of a shell. In order to start building that shell, the larvae need to use carbonate ions from their surroundings. But seemingly all of a sudden, the ocean waters flowing into the hatcheries on the Pacific Coast had a lower concentration of carbonate ions than usual, meaning the larvae missed the dust-to-lentil growth phase that turns them into tiny oysters. As a result, most of them died.

But why had the carbonate ions dipped in the first place? Researchers discovered that the underlying cause was more than a couple years of bad luck or a minor disturbance in tidal patterns. In the mid-aughts, a global shift, which had been quietly altering the ocean's chemistry for hundreds of years, had finally washed up on the shores of the Pacific Coast. And oyster larvae, some of the most vulnerable, valuable, and closely-monitored creatures in the sea, were the first recognized victims of a process that had already started to affect aquatic life across the globe: ocean acidification, a climate change-related process that is gradually lowering pH levels in the water that covers 97 percent of the earth.

The Whiskey Creek hatchery story made the front page of the *Seattle Times* in 2009. Several years later, in 2013, the Royal Swedish Academy of Sciences published a report analyzing the media's treatment of the Whiskey Creek oyster die-offs. In that paper, the authors took a look at the relationship between the hatcheries, the media, and scientific research. What they found was that, at the time of the die-offs, a "landmark" paper had already been published by researchers at Seattle's Pacific Marine Environmental Library showing that ocean acidification was impacting the Pacific Northwest. Which means scientists *knew* the problem was a real threat, but the public hadn't yet caught on. It wasn't the authoritative research paper that got people to pay attention. It was the loss of the seed stock for an entire sector of the economy.

> It took a human story to get the public and local representatives to pay attention to the problems at hand.

The researchers found that it took a human story—a $136 million industry in the United States, employing thousands of people, turned on its head—to get the public and local representatives to pay attention to the problems at hand. Years of scientific papers couldn't accomplish what the Whiskey Creek story demonstrated in short order: When people's lives are affected, legislators hear about it. Washington's then-governor Christine Gregoire soon formed a Blue Ribbon Panel on Ocean Acidification. The panel made policy recommendations, ultimately positioning Washington State as a national leader in ocean acidification research and planning.

Flickr / Louisiana Sea Grant College Program Louisiana State University

Oyster hatcheries raise larvae into seed oysters, pictured above, then sell them to farmers. Once an oyster as reached this size, it can survive in acidified conditions

But despite one state government's proactive stance on changing seas, ocean acidification-related problems have continued to creep toward other parts of the seafood industry. And now, researchers find themselves racing to grasp the implications of a tangled underwater web that includes global warming, ocean acidification, natural seawater patterns, long-term weather events like El Niño and La Niña, and changing fishery management practices.

Ocean water has a birth place. It begins as melting ice somewhere in the North Atlantic, where the newly-formed cold water sinks to the bottom and floats slowly past the equator. It then falls into a rhythm, flowing along the depths and rising to the surface in a global "conveyor belt" that has carried water on the same path for millennia. It takes ten thousand years for a droplet to make its way to the end of the belt, where it emerges, marked with chemical signposts dating further back than written language, off the coast of Washington and Oregon.

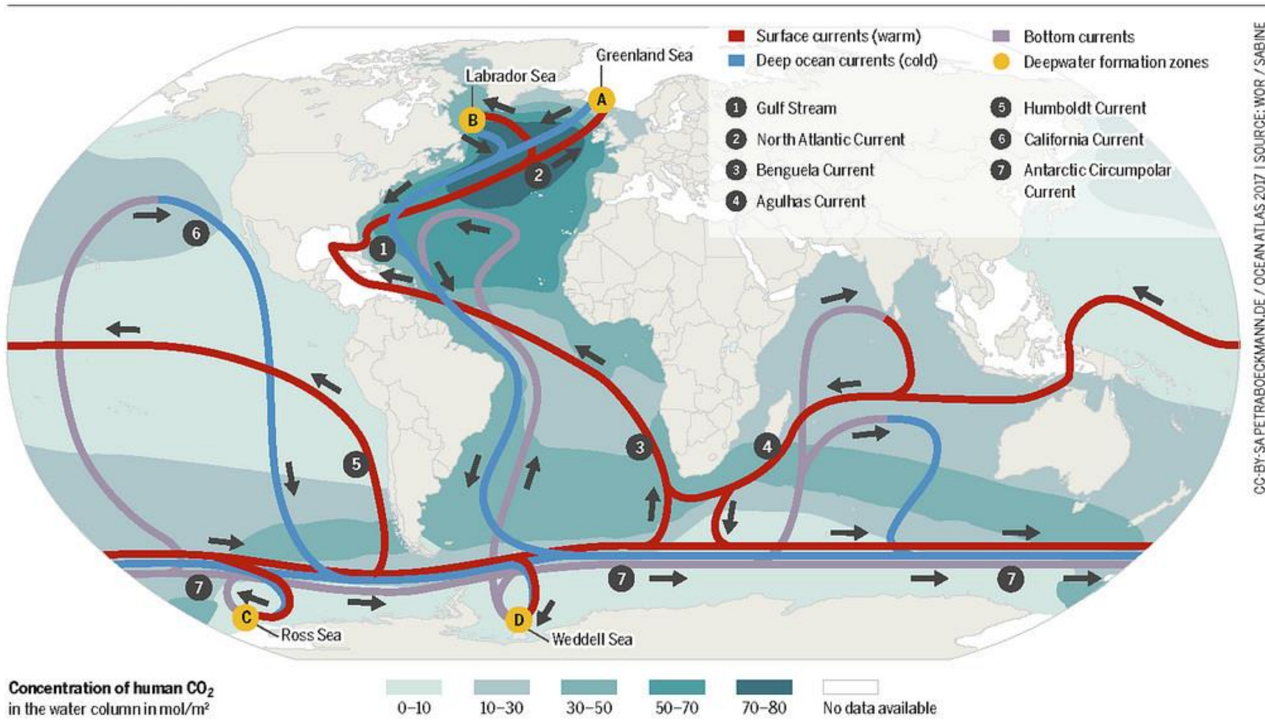
As we know, the ocean itself is also changing. It absorbs about a quarter of the carbon dioxide that humans release into the atmosphere and most of the heat from human activities. Scientists have been studying the *warming* ocean for a while—that's how we learned about sea-level rise and coral bleaching—but until the mid-1990s, no one really understood that the chemical content of the ocean was being altered, too.

> The change in ocean water pH levels likely has a million different effects on marine life.

The term "ocean acidification" refers to a change in oceanic pH. Whereas the pH of the ocean used to be 8.2, it's now hovering around 8.1. And even though that doesn't *sound* like a big difference, pH is measured on a logarithmic scale—which means, for those of us who haven't thought about logs since the SATs, that the ocean is actually about 30 percent more acidic than it used to be. It's expected to hit pH 7.8 by the end of the century.

Here's another way to look at it: The ocean is currently acidifying faster than it has in the last 66 million years.

The Global Conveyor Belt—How the Ocean Stores CO_2



CO_2 entrapment is made possible by large oceanic currents. Working like conveyor belts, they carry warm surface water, which absorbs CO_2, from the tropics in the Atlantic towards the colder poles.
On the way, the water slowly cools and becomes saltier. When it arrives in the Greenland Sea A, the Labrador Sea B, and at the Antarctic coast in the Ross Sea C and the Weddell Sea D, the heavy surface water sinks into the depths, taking the CO_2 with it. The CO_2-rich water then flows back towards the tropics. As it travels, the cold water slowly mixes with the warmer layers above and rises—very slowly—back to the surface.

Flickr / Heinrich-Böll-Stiftung Follow

Water moves between the surface and the ocean floor as it advances along the conveyor belt

It helps to think about pH in human terms. A healthy human body typically has a pH of around 7.4, and it fluctuates very little. A change of 0.3 or 0.4—the same amount the ocean is expected to change by the end of the century—can induce a coma. If body pH rises or falls by 0.5 or more, the results are deadly. So while we don't know exactly what's happening to the organisms that live in the ocean, we know that their environment is changing more rapidly than ever, at rates that would cause serious problems for the human body.

(It's important to note that the ocean isn't actually going to turn to acid by 2100. Shallin Busch, a scientist at NOAA, explains it this way: "The North Pole is a fundamentally cold place, but we say that it's warming. Not that it's going to get warm, but that it's warm*ing.* So you can say the same thing about ocean waters: they're acidifying or becoming more acidic, but they are not acidic themselves.")

But why did ocean acidification appear in the Pacific Northwest before it showed up in Maine?

> The change in ocean water pH levels likely has a million different effects on marine life.

As I described, water moves between the surface and the ocean floor as it advances along the conveyor belt. In the Pacific Northwest, for instance, the water that welled up during the summer the oyster larvae were dying off had last seen the surface about half a century before, north of Hawaii, where it absorbed some of the atmospheric carbon being released at that time. So it's not as though the waters off Seattle are just carrying carbon emissions from the Amazon headquarters they flowed past two days ago—rather, they're carrying the carbon from all the times they welled up to the surface since the Industrial Revolution. "We know that even if all carbon dioxide emissions ceased today, the waters off the Pacific Northwest would continue to acidify for at least another 50 years, so the train is already coming," says Busch.

The water in the Pacific near Washington is at the end of the conveyor belt, and because it's so old it contains a lot of carbon dioxide from the natural decomposition of the organisms that have been dying in it for thousands of years. So when the *added* carbon dioxide from human emissions is mixed with this already-carbon-rich environment during upwelling events, the combination is enough to kill oyster larvae.

Flickr / Louisiana Sea Grant College Program Louisiana State University

The decrease in concentration of carbonate ions—the change that prevented oysters from building their shells—is the most concrete and observable effect of ocean acidification so far

Here's another way to think about it: If the waters in a hatchery are normally somewhere around pH 8.1, they may dip down to pH 7.8 during annual upwelling events when old, carbon-rich water naturally rises to the surface, as happens every summer. But when that old acidic water is mixed with *new* acidic water (the latter being the surface waters impacted by human-released carbon dioxide 50 years ago), the combination can nudge the pH down to, say, 7.7. And it's that small added difference that kills oyster larvae. The human-generated carbon nudges the water across the threshold.

The change in ocean water pH levels likely has a million different effects on marine life, most of which we still know nothing about. The decrease in concentration of carbonate ions—the change that prevented oysters from building their shells—is the most concrete and observable effect of ocean acidification so far. But scientists and fishermen are now trying to tease out all the other, subtler changes. For instance, how a negative impact on one species could affect an entire food chain, or whether or not a change in pH can alter a fish's ability to make decisions. The predictions are all over the place—remember that *Washington Post* story about "super crabs" invading the Chesapeake Bay? (Probably not gonna happen.) But research has advanced rapidly in the last few years. Here's what we know now.

Oysters on the West Coast

> "I was afraid if I didn't do something, then our business would just slowly die."

Once the West Coast hatcheries—which shepherd the larvae through the first stage of life before selling them to farmers as hardy juveniles—diagnosed the problem, they moved quickly to organize a response. The Pacific Coast Shellfish Growers Association recommended that NOAA establish water monitoring systems that give industry players real-time information about the quality of the water flowing into their farms. Hatcheries then used that information to manipulate the water flowing onto their properties—block it when it's too rich in carbon, open the floodgates when the upwelling is over. Many hatcheries have also installed pricey buffering systems that automatically add sodium carbonate to the seawater to balance its chemistry.

But manipulating the incoming water can only work for so long. To escape the West Coast upwelling events, some hatcheries are moving operations as far south as Hawaii.


Flickr / Louisiana Sea Grant College Program Louisiana State University

The oyster industry was the first to be affected by ocean acidification, and it has adapted quickly

Taylor Shellfish—one of the first farms to be impacted by the die-offs—expanded its existing Hawaii hatchery, growing seed oysters and Manila clams. The shellfish are hatched in tropical waters, then shipped northward to mature in places like the Puget Sound.

In 2012, Willapa Bay's Dave Nisbet followed suit. Unlike Taylor Shellfish, which had always relied on its own hatchery for seed oysters, Nisbet's company had depended on harvesting wild oyster seed. He took NOAA's warnings about ocean acidification to heart and decided to build his hatchery in Hawaii, even though it would have been much less expensive to build one in Washington. "I just got nervous," Nisbet told the *Seattle Times* in 2012. "I was afraid if I didn't do something, then our business would just slowly die."

Even though shellfish represent some the most vulnerable populations, they're also the easiest to fix.

Once shellfish pass through the crucial early development stages where they grow their shells, they're more impervious to changes in ocean water. Adolescent oysters, for instance, can thrive in conditions that kill larval clams. West Coast oystermen haven't yet seen acidification-triggered damage to older shellfish.

The oyster industry was the first to be affected by ocean acidification, and it has adapted quickly. In many ways, even though shellfish represent some the most vulnerable populations, they're also the easiest to fix: The infrastructure to hatch farmed shellfish was in place long before ocean acidification became a concern, and individuals can survive the trip from Hawaii to Seattle. But other species—like Dungeness crabs, which aren't farmed, and Alaskan salmon, which migrate—don't have such a simple life cycle.

California’s Dungeness crabs

If larval oysters die-offs were the earliest indicator of the coastal arrival of ocean acidification, then Dungeness crabs are the species researchers and fishermen worry may struggle next. They represent the most valuable fishery on the West Coast, generating $167 million in ex-vessel value in California in 2011. Like oysters, Dungeness crabs are a key driver of the fishing industry, so lucrative that many fishermen rely on them to guarantee an annual income.

Flickr / California Department of Fish and Wildlife

Like oysters, Dungeness crabs rely on carbonate to build their shells. But carbonate isn’t the primary molecule they use

Paul McElhany, a researcher at NOAA, has been testing potential impacts of lowered pH levels on Dungeness crabs. In 2016, his Seattle-based team collected egg-laying female crabs and hatched their young in treated water with varying levels of carbon dioxide.

The researchers’ results would concern any fisherman. At an acidified pH level of 7.5, which has *already* been observed during upwelling events in the Puget Sound, only about a third of the Dungeness crabs survived into the juvenile stage as compared to those that survived in waters with a normal pH. (Remember, the open ocean is at about pH 8.1 now. It’s expected to hit pH 7.8 by the end of the century.)

McElhany says scientists aren’t quite sure *why* the acidified conditions led to such a big drop in crab survival rates. Like oysters, Dungeness crabs rely on carbonate to build their shells. But carbonate isn’t the *primary* molecule they use. Which means the lower survival rate was probably caused by something other than what killed the larval oysters, something scientists have not yet identified.

Ocean acidification *could* be impacting Dungeness crab life cycles already.

And this experiment only manipulated pH levels in a controlled environment. The results, though stark, don't even come close to mimicking conditions in the wild. "Out in the field you've got multiple things going on at the same time because you've got ocean acidification, you also have temperature, climate change, and changes in fishery practice," McElhany explains. If two-thirds of Dungeness crabs are dying inside a tank that doesn't contain predators, fluctuating temperatures, or hard-to-find food, the results in the open ocean could be much worse.

Out in the field, fisherman John Mellor has been keeping an eye on the impossibly complex oceanic patterns that swirl through the crabs' habitat. And while he doesn't think he's witnessed ocean acidification impacting crab populations first hand, he's seen warming waters directly affect the crab catch.

To be clear, ocean acidification *could* be impacting Dungeness crab life cycles already. But because they aren't farmed and because their West Coast habitat has been so abnormal for the last few years—we'll get to that in a second—it's impossible to separate ocean acidification from everything else that's happening along their migration routes.

Flickr / Oregon Department of Fish & Wildlife

Unlike shellfish, which can start their lives in Hawaiian hatcheries to avoid being damaged by a bit of bad water, Dungeness crabs only grow in the wild

But there *have* been recent events that have impacted the Dungeness crab fishery, and they show how a small environmental change (in this case, so small the crabs didn't even notice) can affect the industry as a whole. It's these types of indirect impacts—problems that involve organisms far down the food chain, not the crabs themselves—that researchers like McElhany can’t yet predict in a lab. But that doesn’t mean they’re insignificant.

Between 2014 and 2016, a mass of warm water known as “The Blob” was hanging out along the West Coast. It hasn’t been proven that the blob was a direct result of climate change, though Mellor says many people assume it was. Regardless, scientists expect blob-like conditions to become more common as ocean waters continue to warm.

The blob disrupted local environments, causing die-offs of sea lions and fur seals. It also made a certain type of algae really, really happy. That algae, *Pseudo-nitzschia australis,* produces a toxin called domoic acid. (It has “acid” in its name, but that’s where its relationship to ocean acidification ends.) Humans can’t eat too much domoic acid without getting sick.

The Dungeness crabs aren’t bothered by domoic acid. They can eat a lot of the affected algae and it won’t impact their survival rates. But when they eat the algae, the domoic acid stays in their bodies. And it can cause real problems for humans eating cooked crabs—think short-term memory loss, comas, and seizures.

Crabs are a reminder that our knowledge of this phenomenon is far from complete.

Regulators in California don’t let fishermen catch Dungeness crabs if the crabs have eaten too much algae—no one wants to pass domoic acid poisoning off on some unsuspecting diner. But those restrictions are hard on fishermen. A few years back, Mellor’s season was delayed by five months as he waited for the crab tests to come back clean.

“You can’t really go drive for Uber,” he says, adding that he had to be ready to start fishing at any moment.

To recap: The crabs hadn’t gone anywhere. They were healthy and thriving, and they hadn’t moved from their normal stomping grounds. But warmer-than-usual waters meant higher-than-normal levels of algae, and that algae made the crabs poisonous to humans. This is the kind of butterfly effect that will likely impact Dungeness populations long before pH levels drop down to 7.5, and it’s this type of phenomenon scientists are hoping to predict by running computer simulations of entire food webs in acidified conditions.

Jessica Fu

This year, crab fishing season in Oregon has already been delayed because of domoic acid

Shallin Busch, the scientist at NOAA who studies ocean acidification and fisheries, has been working to predict the effects of ocean-wide change on specific populations. “Basically we created a model of the West Coast food web in the computer and we put in this scenario of ocean acidification from the chemistry change,” she explains. “We looked to see what might happen to fish populations that we harvest under acidification. The take-home answer is that the Dungeness crab harvest was most impacted by our scenarios,” she says. “What this model work was showing was that there’s also likely to be some indirect effect, kind of a food web effect of acidification as well.”

It’ll take years for the gap between lab-generated conclusions and the natural world to narrow.

Unlike shellfish, which can start their lives in Hawaiian hatcheries to avoid being damaged by a bit of bad water, Dungeness crabs only grow in the wild. “The crabs walk in and out of the canyons, and then they’ll walk up onto the shelf, and they feed on the clam beds and the worm beds and whatever they can eat, and then they typically will mate in February, March, April—and then after they’re done mating, they eat a little more and then molt,” Mellor says. All the while, they’re migrating throughout different parts of the ocean floor.

This year, Mellor’s fishing season started on time. Crab fishermen in Oregon weren’t so lucky—their season has already been delayed because of domoic acid.

If oysters show the most direct and observable link between ocean acidification and survival rates, the crabs are a reminder that our knowledge of this phenomenon is far from complete. It’ll take years for the gap between lab-generated conclusions and the natural world to narrow. In the meantime, crab populations will continue to live in a changing habitat.

Elsewhere

Though we have the most data about oysters and Dungeness crabs, researchers are also focusing on the potential impacts of ocean acidification on other commercially-valuable species. McElhany says there's some preliminary evidence that shows elevated acidity may impact the part of a salmon's brain that helps it avoid predators—another incidence of a subtle change that could have catastrophic consequences. Earlier this month, biologists began sounding the alarm bells about Alaska's red king crabs, warning that they could be extinct in the next century. King crabs struggle to build their shells in acidified conditions, and researchers hypothesize that they simply can't generate enough energy to maintain a survivable internal pH as external pH levels continue to fall.

Unsplash / Charlotte Coneybeer

There's a little hope, though: In the king crab trials, a few of the juveniles made it out alive in lab conditions that simulated Alaskan waters a hundred years from now. Those crabs may be able to pass their traits onto their young, creating a new generation of crustaceans that can survive in changing waters.

What can we do about the impact of ocean acidification right now? "We don't have that answer for you," Busch says. "We're hoping in the future that we will. There's this massive global effort to better understand species sensitivity, better understand ecosystem changes, do better monitoring. That's one thing."

ENVIRONMENT, FARM, HEALTH, POLICYDUNGENESS CRABSOCEAN ACIDIFICATIONOYSTERSSHELLFISHWASHINGTON STATE

H. Claire Brown

A North Carolina native, Claire Brown joins The New Food Economy after working on the editorial team at *Edible Manhattan* and *Edible Brooklyn.* She won the New York Press Club's Nellie Bly Cub Reporter award in 2017. Follow her at @hclaire_brown.

Exhibit 7

http://www.dailymail.co.uk/sciencetech/article-2208953/Shock-report-claims-100m-people-die-economic-growth-drop-3-2-2030-climate-change-ignored.html

Ignore climate change and 100m people will die by 2030, shocking new report claims

By DAILY MAIL REPORTER
PUBLISHED: 26 September 2012 |

More than 100 million people will die and global economic growth will be cut by 3.2 percent of gross domestic product (GDP) by 2030 if the world fails to tackle climate change, a report commissioned by 20 governments has claimed.

As global average temperatures rise due to greenhouse gas emissions, the effects on the planet, such as melting ice caps, extreme weather, drought and rising sea levels, will threaten populations and livelihoods, said the report conducted by humanitarian organisation DARA.

It calculated that five million deaths occur each year from air pollution, hunger and disease as a result of climate change and carbon-intensive economies, and that toll would likely rise to six million a year by 2030 if current patterns of fossil fuel use continue.

More than 90 percent of those deaths will occur in developing countries, said the report that calculated the human and economic impact of climate change on 184 countries in 2010 and 2030.

It was commissioned by the Climate Vulnerable Forum, a partnership of 20 developing countries threatened by climate change.

'A combined climate-carbon crisis is estimated to claim 100 million lives between now and the end of the next decade,' the report said.

It said the effects of climate change had lowered global output by 1.6 percent of world GDP, or by about $1.2 trillion a year, and losses could double to 3.2 percent of global GDP by 2030 if global temperatures are allowed to rise, surpassing 10 percent before 2100.

It estimated the cost of moving the world to a low-carbon economy at about 0.5 percent of GDP this decade.

British economist Nicholas Stern told Reuters earlier this year investment equivalent to 2 percent of global GDP was needed to limit, prevent and adapt to climate change.

His report on the economics of climate change in 2006 said an average global temperature rise of 2-3 degrees Celsius in the next 50 years could reduce global consumption per head by up to 20 percent.

Temperatures have already risen by about 0.8 degrees Celsius above pre-industrial times.

Almost 200 nations agreed in 2010 to limit the global average temperature rise to below 2C (3.6 Fahrenheit) to avoid dangerous impacts from climate change.

But climate scientists have warned that the chance of limiting the rise to below 2C is getting smaller as global greenhouse gas emissions rise due to burning fossil fuels.

The world's poorest nations are the most vulnerable as they face increased risk of drought, water shortages, crop failure, poverty and disease.

On average, they could see an 11 percent loss in GDP by 2030 due to climate change, DARA said.

'One degree Celsius rise in temperature is associated with 10 percent productivity loss in farming.

'For us, it means losing about 4 million metric tonnes of food grain, amounting to about $2.5 billion.

'That is about 2 percent of our GDP,' Bangladesh's Prime Minister Sheikh Hasina said in response to the report.

'Adding up the damages to property and other losses, we are faced with a total loss of about 3-4 percent of GDP.'

Even the biggest and most rapidly developing economies will not escape unscathed.

The United States and China could see a 2.1 percent reduction in their respective GDPs by 2030, while India could experience a more than 5 percent loss.

The full report is available here:
http://daraint.org/climate-vulnerability-monitor/climate-vulnerability-monitor-2012/report/

Executive Summary here:
http://www.daraint.org/wp-content/uploads/2012/09/EXECUTIVE-AND-TECHNICAL-SUMMARY.pdf

Exhibit 8

REPORT: CLIMATE CRISIS ALREADY CAUSING UNPRECEDENTED DAMAGE TO WORLD ECONOMY; HUMAN IMPACT ON LARGE-SCALE

- New and comprehensive assessment of the costs of climate change

- Inaction on climate change already causing over one trillion dollars in losses

- Costs to escalate rapidly: global GDP stunted by over 3 percent by 2030 – crisis to increasingly hold back growth if urgent action is not taken

- Climate change and carbon economy linked to 5 million deaths each year

- High-level political, scientific and economic leaders call for international action to halt surge in losses to human life and the world economy hitting all nations

NEW YORK, Wednesday 26 September 2012 – DARA and Climate Vulnerable Forum report: Most comprehensive ever assessment of the current global impact of climate change released today.

20 governments commissioned the independent report, the first of its kind to show that tackling the global climate crisis would already reap significant economic benefits for world, major economies and poor nations alike.

"*Climate Vulnerability Monitor*" study's findings point to unprecedented harm to human society and current economic development that will increasingly hold back growth, on the basis of an important updating and revision of previous estimates of losses linked to climate change.

KEY FINDINGS INCLUDE THE FOLLOWING ESTIMATES:

- Climate change and a carbon-intensive economy considered a leading global cause of death today, responsible for 5 million deaths each year – 400,000 due to hunger and communicable diseases aggravated by climate change and 4.5 million carbon economy deaths due mainly to air pollution
- Failure to act on climate change *already costs* the world economy 1.6% of global GDP amounting to 1.2 trillion dollars in forgone prosperity a year
- Rapidly escalating temperatures and carbon-related pollution will double costs to 3.2% of world GDP by 2030
- Losses for lower-income countries are already extreme: 11% of GDP on average for Least Developed Countries already by 2030
- Major economies are heavily hit: in less than 20 years China will incur the greatest share of all losses at over 1.2 trillion dollars; the US economy will be held back by more 2% of GDP; India, over 5% of its GDP

- Economic losses dwarf the modest costs tackling climate change: emission reductions at just 0.5% of GDP for the next decade; and support to the vulnerable: a minimum of 150 billion dollars per year for developing countries

Climate Vulnerable Forum Chair, Bangladesh – one of the largest newly-emerging economies in Asia – represented by **Prime Minister Sheikh Hasina** officially launched the report at a major diplomatic event to coincide with the 67th session of United Nations General Assembly. Commenting on the report she said:

> *"One degree Celsius rise in temperature is associated with 10% productivity loss in farming. For us, it means losing about four million metric tonnes of food grain, amounting to about US$ 2.5 billion. That is about 2% of our GDP. Adding up the damages to property and other losses, we are faced with a total loss of about 3-4% of GDP. Without these losses, we could have easily secured much higher growth."*
>
> *"After seventeen years of international negotiations, we are still without any meaningful agreement or action to reduce global warming. As a climate vulnerable country, every day we see and feel the ramifications of that inaction as outlined in the Climate Vulnerable Monitor. But experts have struggled to tie all the pieces together to design a clear picture of climate vulnerability. This report examines impacts linked to climate change in some new ways and attempts to draw new conclusions. We did not have access to this information until now. Of course, experts may call into question this or that aspect of the Monitor's findings, but we are certain subsequent research will continue to reaffirm the broad conclusions of the report. Its publication is a milestone for the climate negotiations. It is our hope it will help redirect efforts to effectively address the harms being done to today's economy. We continue to work with all governments and other stakeholders to bring about a fair and just outcome to the negotiations."*

The report is the second to be issued by an ongoing international research program on climate-related vulnerability mandated to the independent humanitarian and development research organization, DARA. Its expanded assessment of the costs of inaction on climate change presents a new and original assimilation of the latest scientific evidence, research and data in a survey of thirty-four indicators of climate-related concern. The study estimates human and economic impacts for 184 countries in 2010 and 2030 across a wide range of separate effects. Indicators of impact range from issues such as hunger and skin cancer, to permafrost thawing and sea-level rise, indoor and outdoor air pollution, and fisheries, biodiversity and forest deterioration. Constraints on labor productivity, imposed by rising heat, are the largest single impact due to climate change and a new component of the analysis.

High-level and technical panels of over 50 leading scientists, economists, and policy experts, including former heads of government, reviewed the report whose development also involved field-based research in Africa and Asia.

Report Panel member, **DARA Trustee and Former President of Costa Rica José María Figueres** said today:

> *"1.3 billion people are still fighting their way out of the most extreme forms of poverty while major economies are today fighting their way out of crippling financial and economic crises. We simply cannot afford to part with more growth. The prospect of economic losses that rise with every decade could destabilize the world economy far before the worst impacts of climate change set in. Governments and international policy makers must act decisively to combat the spiraling costs to national and global GDP resulting from inaction on climate change. The Monitor shows how failure to do so has already caused unprecedented damage to the world economy and threatens human life across the globe. With the investment required to solve climate change already far below the estimated costs of inaction, no doubt remains as to the path worth taking."*

The new Monitor report, entitled "A Guide to the Cold Calculus of A Hot Planet," juxtaposes on the one hand the large-scale anticipated increases in fossil fuel consumption over the coming decades with the enormous human and developmental consequences of this. However, it also points out that decisions taken on cold monetary terms alone would actually favour strong action on climate change globally and regionally.

The report outlines how the first edition of the Monitor is already used as a tool by development, humanitarian and aid agencies concerned with addressing the growing impact of climate change around the world, as well as investment and security analysts among others.

Ends

FOR ADDITIONAL COMMENT, INFORMATION OR TO REQUEST AN INTERVIEW WITH A DARA/FORUM SPOKESPERSON, PLEASE CONTACT:

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About the Monitor

The *Climate Vulnerability Monitor* measures the global impact of climate change and the carbon economy at a national level. It calculates and compares the vulnerability for 184 countries in four areas of impact (environmental disasters, habitat change, health impact and industry stress) using 34 climate and carbon related indicators. The monitor uses five levels of vulnerability, from acute to low, to compare and contrast nations.

The first Monitor was launched in 2010 to assess the effects of global climate change on nations up to 2030. It uses current peer-reviewed scientific research, in-country field research and critical input from two separate external advisory bodies.

About DARA

Founded in 2003, DARA is an international organization headquartered in Madrid, Spain, committed to improving the effectiveness of aid for vulnerable populations suffering from conflict, disasters and climate change.

It is an impartial, non-partisan, non-profit entity independently governed by a foundation Board of Trustees and actively engaged in field research and evaluation work of aid programs and operations in developing countries across five continents. It also produces and issues specialized publications and data in particular on aid accountability and effectiveness issues, as well as emerging strategic concerns for the development, humanitarian and disaster reduction domains.

DARA's Climate Vulnerability Initiative is mandated to develop the Monitor as an independent and politically impartial report and convenes the external advisory bodies that provide third-party guidance and review inputs to this process.

www.daraint.org

About the Climate Vulnerable Forum

Founded in 2009, the Climate Vulnerable Forum is a semi-formal government cooperation group of developing countries facing high degrees of insecurity due to climate change and active in seeking a resolution to the climate crisis.

The Forum has called for ambitious outcomes in international climate change policy, such as setting the temperature increase goal at 1.5° Celsius (2.7° Fahrenheit) which was subsequently also adopted by other groups of countries and played an important boundary definition role in the UN climate negotiations at Copenhagen in 2009. The Forum has advocated for and insisted on accountability to decisions taken in international arena regarding climate change and sustainable development and its members have committed to pursue domestic low-carbon and even carbon neutral development pathways.

The Forum currently has 20 members and meets periodically at head of government, ministerial and delegate levels. The Monitor is an analytical input and communication tool for Forum members, and the two country studies included in this report were undertaken in member countries, Ghana and Vietnam.

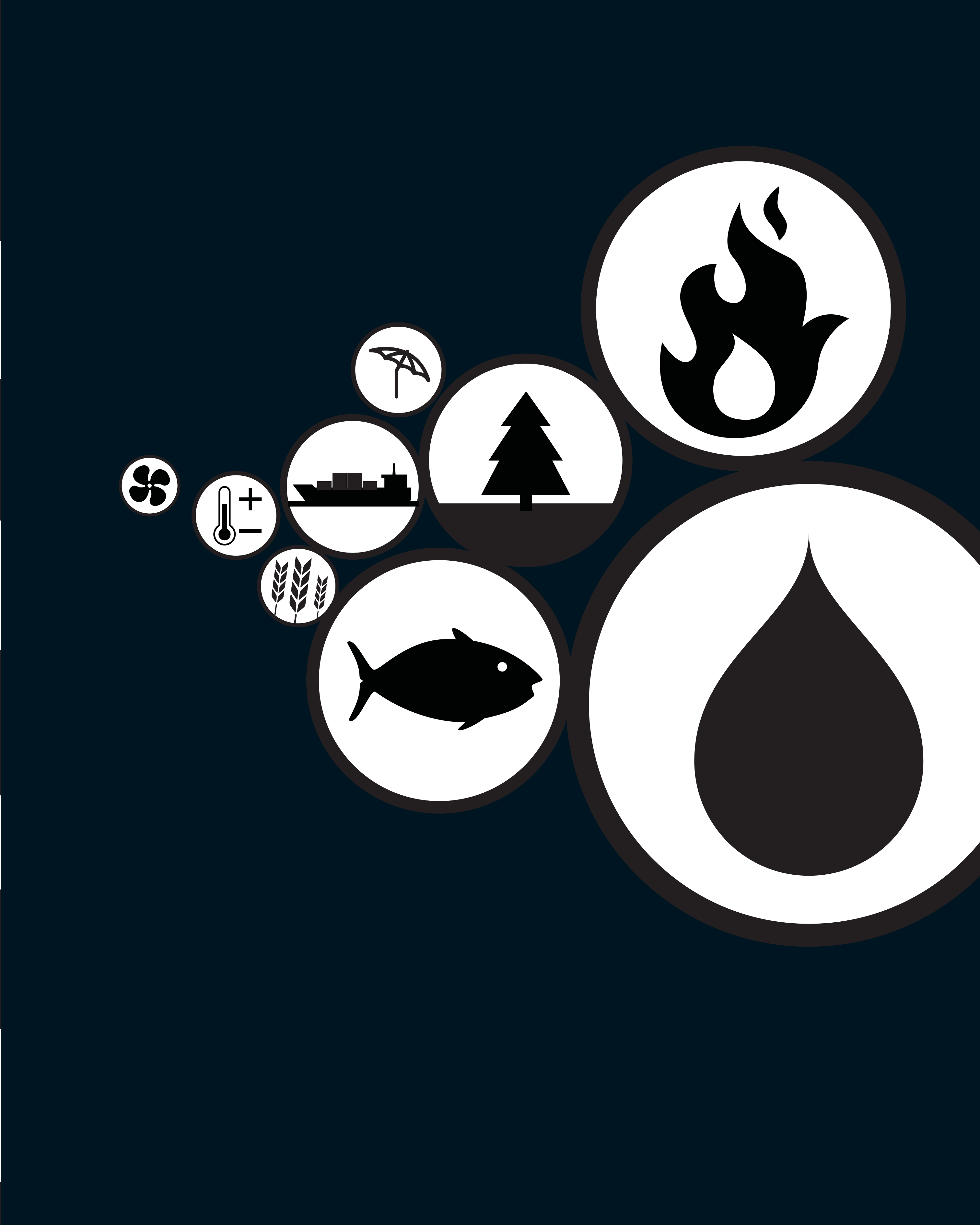
Exhibit 9

2ND EDITION CLIMATE VULNERABILITY MONITOR

A GUIDE TO THE COLD CALCULUS OF A HOT PLANET

Climate Vulnerable Forum

DARA

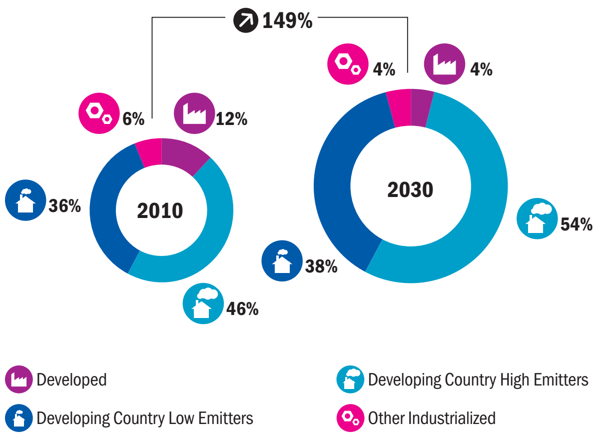


EXECUTIVE SUMMARY

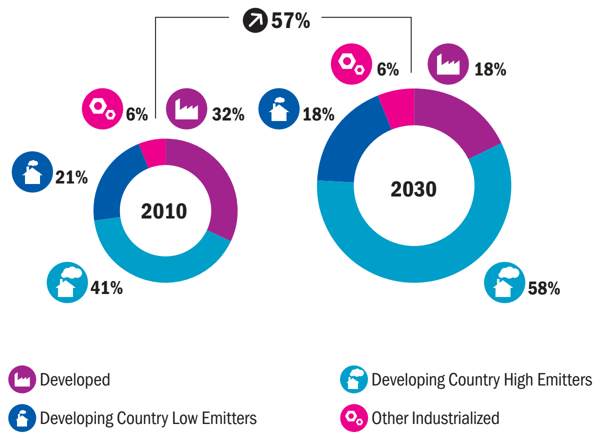
This report provides a reassessment of the human and economic costs of the climate crisis. The reassessment is based on a wealth of the latest research and scientific work on climate change and the carbon economy, research that is assimilated as a part of this report.

THE MAIN FINDING OF THIS REPORT IS THAT CLIMATE CHANGE HAS ALREADY HELD BACK GLOBAL DEVELOPMENT: IT IS ALREADY A SIGNIFICANT COST TO THE WORLD ECONOMY, WHILE INACTION ON CLIMATE CHANGE CAN BE CONSIDERED A LEADING GLOBAL CAUSE OF DEATH.

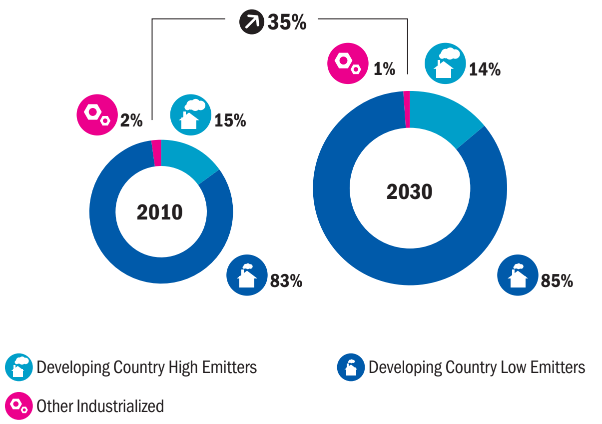
CLIMATE – TOTAL COSTS



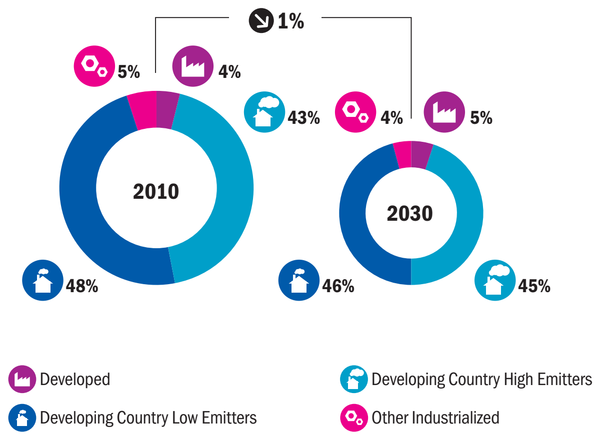
CARBON – TOTAL COSTS



CLIMATE – TOTAL DEATHS



CARBON – TOTAL DEATHS



This report estimates that climate change causes 400,000 deaths on average each year today, mainly due to hunger and communicable diseases that affect above all children in developing countries. Our present carbon-intensive energy system and related activities cause an estimated 4.5 million deaths each year linked to air pollution, hazardous occupations and cancer.

the world's oceans, the slow response of the carbon cycle to reduced CO_2 emission and limitations on how fast emissions can actually be reduced.[1]
The world economy therefore faces an increase in pressures that are estimated to lead to more than a doubling in the costs of climate change by 2030 to an estimated 2.5% of global GDP. Carbon economy costs also increase over this same period so that

OVERALL COSTS

	Losses 2010, Bln PPP corrected USD	Losses 2010, % of GDP	Net Losses, % of GDP 2010	Net Losses, % of GDP 2030
Climate	696	0.9%	0.8%	2.1%
Carbon	542	0.7%	0.7%	1.2%
World	**1,238**	**1.7%**	**1.6%**	**3.2%**

Climate change caused economic losses estimated close to 1% of global GDP for the year 2010, or 700 billion dollars (2010 PPP). The carbon-intensive economy cost the world another 0.7% of GDP in that year, independent of any climate change losses. Together, carbon economy- and climate change-related losses amounted to over 1.2 trillion dollars in 2010.
The world is already committed to a substantial increase in global temperatures – at least another 0.5° C (1° F) due to a combination of the inertia of

global GDP in 2030 is estimated to be well over 3% lower than it would have been in the absence of climate change and harmful carbon-intensive energy practices.
Continuing today's patterns of carbon-intensive energy use is estimated, together with climate change, to cause 6 million deaths per year by 2030, close to 700,000 of which would be due to climate change. This implies that a combined climate-carbon crisis is estimated to claim 100 million lives between now and the end of the next decade. A significant

NUMBER OF DEATHS

		2010	2030
Climate	Diarrheal Infections	85,000	150,000
	Heat & Cold Illnesses	35,000	35,000
	Hunger	225,000	380,000
	Malaria & Vector Borne Diseases	20,000	20,000
	Meningitis	30,000	40,000
	Environmental Disasters	5,000	7,000
Carbon	Air Pollution	1,400,000	2,100,000
	Indoor Smoke	3,100,000	3,100,000
	Occupational Hazards	55,000	80,000
	Skin Cancer	20,000	45,000
World		**4,975,000**	**5,957,000**

TECHNICAL SUMMARY

The Monitor presents a new and original analysis, synthesizing the latest research and scientific information on the global impact – including benefits and losses – of climate change and the carbon economy in economic, environmental and health terms. Climate change already causes 400,000 deaths each year on average. The present carbon-intensive economy moreover is linked to 4.5 million deaths worldwide each year. Climate change to date and the present carbon economy are estimated to have already lowered global output by 1.6% of world GDP or by around 1.2 trillion dollars (2010 PPP). Losses are expected to increase rapidly, reaching 6 million deaths and 3.2% of GDP in net average global losses by 2030. If emissions continue to increase unabated in a business-as-usual fashion (similar to the new IPCC RCP8.5 scenario), yearly average global losses to world output could exceed 10% of global GDP before the end of the century, with damages accelerating throughout the century. The costs of climate change and the carbon economy are already significantly higher than the estimated costs of shifting the world economy to a low-carbon footing – around 0.5% of GDP for the current decade, although increasing for subsequent decades.[1]
This report and scientific literature imply adaptation costs

share of the global population would be directly affected by inaction on climate change.

Global figures mask enormous costs that will, in particular, hit developing countries and above all the world's poorest groups. Least Developed Countries (LDCs) faced *on average* in excess of 7% of forgone GDP in 2010 due to climate change and the carbon economy, as all faced inequitable access to energy and sustainable development.

Over 90% of mortality assessed in this report occurs in developing countries only – more than 98% in the case of climate change.

Of all these losses, it is the world's poorest communities within lower and middle-income countries that are most exposed. Losses of income among these groups is already extreme. The world's principal objectives for poverty reduction, the Millennium Development Goals (MDGs), are therefore under comprehensive pressures, in particular as a result of climate change.

The impact for rural and coastal communities in the lowest-income settings implies serious threats for food security and extreme poverty (goal 1 of 8), child health and the ability of children to attend school (goals 2 and 4), maternal health and women's development (goals 3 and 5), the prevalence of infectious diseases (goal 6) and, through water, fisheries and biodiversity impacts, environmental sustainability (goal 7). Furthermore, in a difficult fiscal environment, the advent of climate change has pressured governments to divert Official Development Assistance (ODA) funds from other development commitments and activities in an attempt to provide support for climate change concerns, including to a marginal degree, for helping vulnerable communities adapt to climate change. The Green Climate Fund, agreed upon in incrementally greater detail at the successive international climate talks at Copenhagen, Cancún and Durban, faces an economic environment of declining ODA tied to acute fiscal crises across a host of the world's wealthiest economies (see: climate finance). These developments have ultimately compromised the global partnership for development (goal 8). Lag areas towards MDG achievement also align very closely with the most pronounced vulnerabilities resulting from climate change: sub-Saharan Africa, small island developing states, and South Asia in particular.

Poverty reduction efforts are in peril as the potential temperature increase the world is already committed to has only begun to be realized, and the world's major economies are in no way spared. The United States, China and India in particular are expected to incur enormous losses that in 2030 for these three countries alone will collectively total 2.5 trillion dollars in economic costs and over 3 million deaths per year, or half of all mortality – the majority in India and China.

The whole world is affected by these comprehensive concerns: 250 million people face the pressures of sea-level rise; 30 million people are affected by more extreme weather, especially flooding; 25 million people are affected by permafrost thawing; and 5 million people are pressured by desertification. The pressures that these combined stresses put on affected communities are immense and force or stimulate the movement of populations. As is highlighted in the Ghana country study in this report, they can also fuel violence and an erosion of the social and economic fabric of communities.

The impact of climate change on Labour Productivity is assessed here as the most substantial economic loss facing the world as a result of climate change. A large proportion of the global workforce is exposed to the incessant increase in heat, with the number of very hot days and nights increasing in many places by 10 days a decade.[2] Developing countries, and especially the lowest-income communities, are highly vulnerable to these effects because of geographical location – northern countries like Scandinavia, it is assumed, *benefit* from improved labour productivity due to warmer weather – but also because their labour forces have the highest proportion of non-climate controlled occupational environments.[3]

Global productivity in labour is surging due to technological advances and a shift of emphasis from agricultural activities to an industrial and service sector focus for most developing countries, among other key developments.[4] Climate change, however, holds back the full extent of productivity gains the world would otherwise enjoy.[5] In this way, the

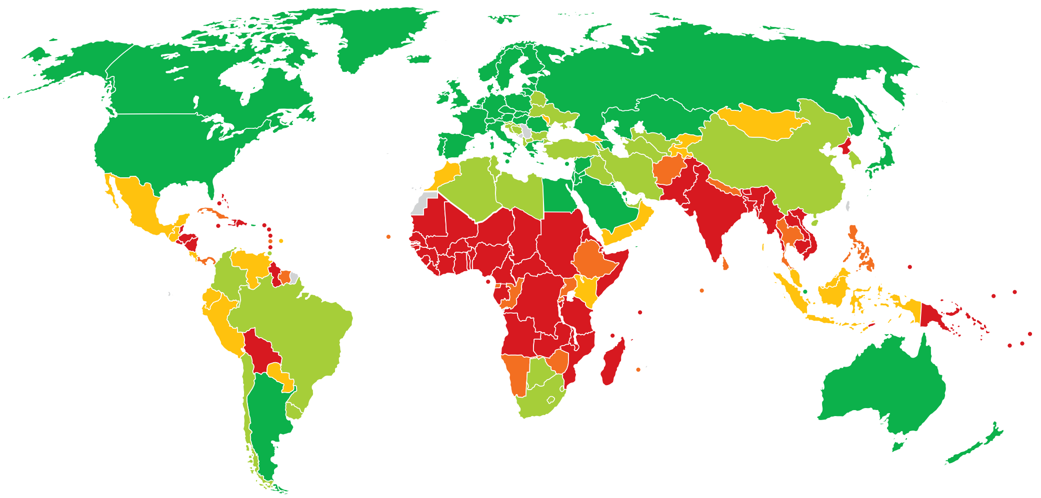
to be at least 150 billion dollars per year today for developing countries, rising to a minimum of more than 1 trillion dollars per year by 2030. These costs are, however, considerably lower than costs of damages to developing countries estimated here, so adapting to climate change is very likely a cost-effective investment in almost all cases and should be central to any climate change policy.

Beyond adaptation, this report also emphasizes the urgency of mitigating key risks: tackling food security, indoor fires/smoke, air pollution and other health issues such as diarrheal illnesses, malaria and meningitis that are all urgent priorities for lessening the extent of the human toll of this crisis.

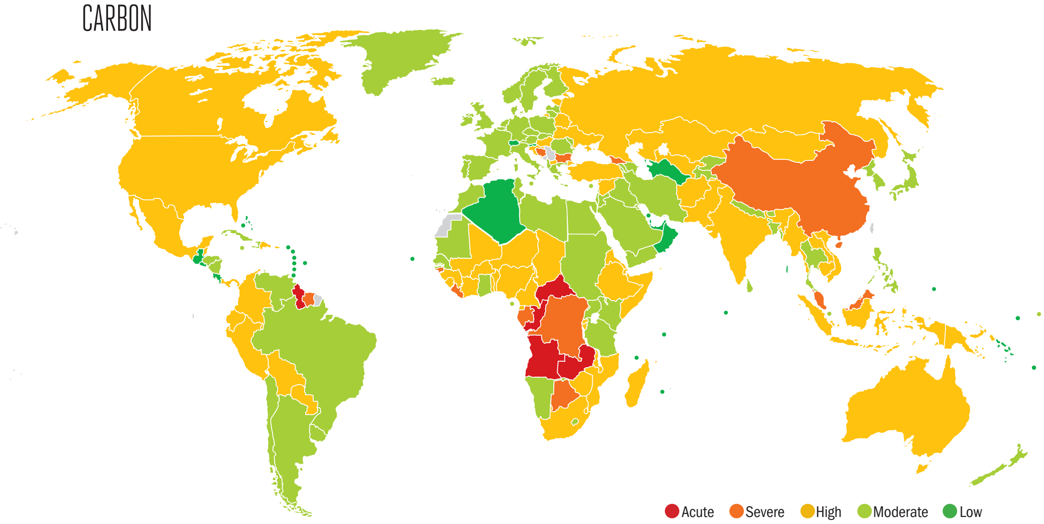
With costs due both to unabated climate change and the carbon economy expected to rise rapidly over the course of this century, tackling climate change by reducing emissions yields net benefits to the world economy in monetary terms – amounting to around a 1% higher GDP for the entirety of the 21st century (net present value at a 3% discount rate). World net benefits from action on climate change are insensitive to discount rates from 0.1% to 20% (the highest tested). Even the most ambitious reductions in emissions aimed at holding warming below 2°C (e.g. 400ppm CO_2e/IPCC AR5 RCP2.6 scenario) generates economic benefits for the costs of climate change are hidden, which helps to explain in part how their full extent may have been missed. Even so, not all have benefitted from fast expanding labour productivity: labour productivity is a core indicator for MDG 1 (on extreme poverty and hunger), for instance, where little progress has been registered in many developing regions of the world, in particular for sub-Saharan Africa and the Pacific.[6] Not one country is *invulnerable* to the combined effects of climate change and the carbon economy. Inaction on climate change penalizes every country in the world, just as all are set to gain from action

MULTI-DIMENSIONAL VULNERABILITY

CLIMATE



CARBON



world economy after accounting for the costs of reducing emissions (mitigation costs). Limiting warming to this level would limit human, territorial and ecological damage as well as other concerns, such as climate-induced forced movement of human populations.

Over 98% of all climate change mortality and over 90% of all carbon economy related mortality is in developing countries: between 80% and 90% of all economic costs are projected to fall on developing countries. The most extreme effects of climate change are estimated to be felt by the Least Developed Countries, with average GDP losses of 8% in 2030. With respect to carbon economy effects, inequitable access to sustainable development sees Least Developed Countries again incurring the highest relative losses at over 3% of GDP, while between two thirds and three quarters of all carbon economy costs are borne by developing countries.

When the costs of climate change and the carbon economy estimated here are combined, not one country in the world is left unharmed. In terms of regional incentives to tackle climate change, every region is estimated to experience net economic benefits from action on climate change even for the highest levels of action.

The Monitor only analyses incremental impacts as a result of climate change, or changes in the frequency of well-known stochastic events, such as floods and landslides. Not assessed here in any way are potential catastrophic impacts that could occur due to more rapid climate change fuelled on climate change. Moreover, the vulnerability of the world is shifting with every passing decade. Countries once resilient to marginal weather effects increasingly realize susceptibilities to a changed climate as the increase in heat and associated effects continue to reach new extremes.

Some quite serious damage is now unavoidable, but certain losses can still be reduced in the short term. In particular, human costs can be transferred to economic costs. This can be achieved through programmes aimed at reducing rural poverty – at the origin of hunger deaths and many communicable diseases afflicting the world's poorest groups, with risks that worsen with climate change. Or it can be achieved by ensuring clean air regulations, safer working conditions and modern energy options for people at risk due to carbon-intensive forms of energy. All these measures will save lives but cost money.

Economic losses themselves can also be lessened. A major recent review of humanitarian assistance work noted that Mozambique had requested 3 million dollars from the international community for flood preparations. That sum went unsecured, and 100 million dollars was subsequently spent on emergency flood response.[7] Investment in agriculture might also be cost-effective if the costs of supporting upgraded farming were to generate more benefits (in productivity, output) than the initial outlay.[8]

There are, however, limits to the ability of populations to adapt. The oceans can hardly be refrigerated against marine stresses.[9] Desert encroachment can be prevented but rarely reversed, and if so, generally at great expense.[10] It might be possible to protect a beach, but concrete polders could well be to the detriment of an area's authentic charm and so to the value of properties.

A low-carbon, renewable economy – of hydro, wind, solar, geothermal, tidal and other innovative sources of energy – now competes with the most carbon-intensive forms of power generation in the open market, where they constitute around 10% of the global energy mix today.[11] Shifting the balance in favour of low-carbon energy has been estimated to cost approximately 0.5% or less of GDP for the current decade.[12]

The carbon economy is largely responsible for the incredible growth in overall wealth society has amassed over the last 200 years, although, according to the World Bank, 1.3 billion people continue to remain trapped in dire poverty.[13]

Regardless, an economic system developed to support a global population of 1 or 2 billion people in the 19th century is ill suited to a global population in excess of 7 billion and growing.[14]

The climate challenge runs in parallel to other key global developments: a growing world population, a major propensity to urbanization, and structural

by feedbacks such as a release of Arctic methane deposits, more rapid sea-level rise that could result from the disintegration of the West Antarctic Ice Sheet or large-scale climatic disruptions such as the collapse of ocean circulation mechanisms, all of which are understood to pose significantly larger human, economic and ecological risks than anything portrayed here. The possibilities of these events are by no means ruled out, with risks increasing substantially with warming.[2] Other economists have therefore factored such risks into their economic analysis to a degree.[3]

Only with the deep and sustained emissions reductions spelled out in the lowest of the new IPCC RCP 2.6 scenario is there a reasonable chance (comfortably over 50%) of not exceeding the internationally accepted "safety" temperature threshold of 2°C global mean warming above preindustrial.[4] Given the clear human, ecological and,

REGIONAL COST BENEFIT ANALYSIS, 2010-2100** PERCENTAGE OF GLOBAL GDP (NOMINAL), NET PRESENT VALUE AT 3% DISCOUNT RATE

	Climate + Carbon Costs				Highest Action		High Action		Moderate Action		Net Benefit		
Region	**No Action**	**Highest action (400 ppm)**	**High action (450 ppm)**	**Moderate action (550 ppm)**	**Avoided costs***	**Mitigation costs**	**Avoided costs***	**Mitigation costs**	**Avoided costs***	**Mitigation costs**	**Highest action**	**High Action**	**Moderate action**
USA	3.0%	1.0%	1.0%	1.5%	2.0%	1.5%	2.0%	1.0%	1.5%	0.5%	0.5%	1.0%	1.0%
Japan	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.0%	0.0%	0.0%
Russia	4.5%	1.5%	1.5%	2.0%	3.0%	2.0%	3.0%	2.0%	2.5%	2.5%	1.0%	1.0%	0.0%
China	4.5%	2.0%	2.0%	2.5%	2.5%	2.0%	2.5%	1.5%	2.0%	1.0%	0.5%	1.0%	1.0%
India	11.0%	5.0%	5.5%	6.5%	6.0%	3.0%	5.5%	2.0%	4.5%	0.5%	3.0%	3.5%	4.0%
EU27	1.0%	0.5%	0.5%	0.5%	0.5%	1.0%	0.5%	0.5%	0.5%	0.5%	0.0%	0.0%	0.0%
ROW	8.5%	3.5%	3.5%	4.5%	5.5%	2.0%	5.0%	1.0%	4.5%	0.5%	3.5%	4.0%	3.5%
World***	4.0%	1.5%	1.5%	2.0%	2.5%	1.5%	2.0%	1.0%	2.0%	0.5%	1.0%	1.0%	1.0%

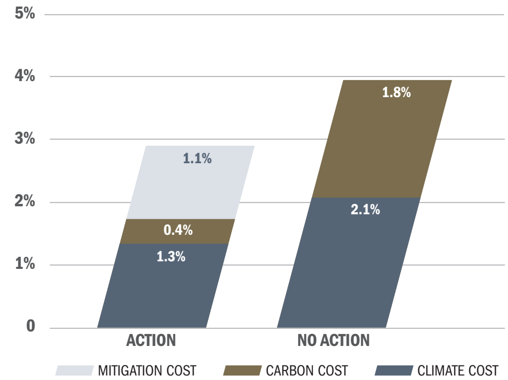
*Avoided costs: No action (A1B +8.5) minus reduced ppm scenario (400 ppm C02e: RCP2.6; 450 ppm: RCP2.9; 550 ppm: SRES B1)

** Discounted (3%) sum of costs and GDP – mitigation costs from Edenhofer et al., 2010 (regional: Remind + Poles)

*** Median value of all 5 scenarios (Edenhofer et al., 2010)

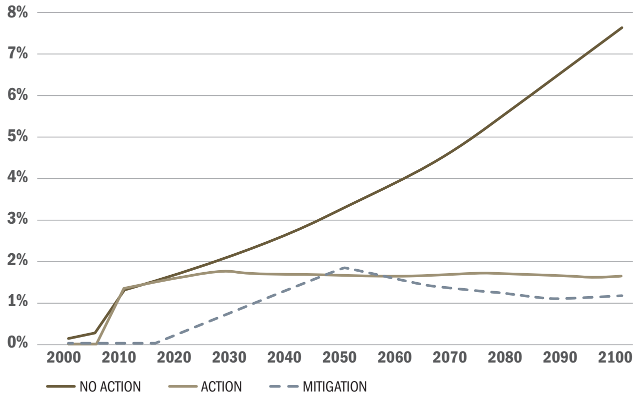
ACTION VERSUS INACTION OVER THE 21ST CENTURY

NPV OF GLOBAL CLIMATE/CARBON COSTS AND MITIGATION COSTS RELATIVE TO GDP (NOMINAL 2010-2100, 3% DISCOUNT RATE)



21ST CENTURY COSTS OF CLIMATE CHANGE ACTION, INACTION AND MITIGATION

PERCENTAGE (%) OF NOMINAL GDP NON-DISCOUNTED



Action equals 450 ppm (RCP 2.9) No action equals mid-point of 2 non-stabilization scenarios (RCP 8.5 and SRES A1B)

shifts occurring in economies around the world. All of these tendencies – most pronounced in developing countries, in particular the process of industrialization now spreading more and more widely[15] – can worsen or attenuate vulnerabilities to climate change or the carbon economy.

In order to understand the fuller implications of this study and to make its findings comparable with previous works that take on longer-term perspectives, the costs of climate change and the carbon economy were also estimated for the period up until 2100. On this basis, business-as-usual development could see the costs of inaction exceeding 10% of global GDP in losses prior to 2100.

Reducing emissions results in net benefits for society in every case because the costs of a low-carbon transition are more than outweighed by averted losses due to climate change and the carbon economy.

In the global context, the highest level of emission reductions results in similar global benefits to lower levels of action. However, the highest action sees fewer negative impacts on society –from human health to biodiversity and for the world's oceans – but requires slightly greater investments in low-emission forms of energy. Less ambitious action means accepting larger scales of human and ecological impacts.

The regional analysis of costs and benefits differs little in fundamental terms from the global analysis: all regions benefit from climate action in economic terms. Most regions find optimal climate action in the high-action scenario. The highest action to reduce emissions also limits the risks of crossing tipping points leading to large-scale climate disruptions.[16] Less ambitious action on climate change does not: moderate action on climate change has a high chance of exceeding the accepted international temperature goal of holding warming below 2° C (3.6° F) above pre-industrial levels.[17] The most vulnerable countries have called for warming to be limited below 1.5° C above pre-industrial levels as they believe 2° C is far too damaging and a risk to their survival.

Neither should the risks of catastrophic impacts be discarded as heresy: new research has highlighted great risks associated with *heat*, as opposed to ocean-related immersion of countries, with heat risks concerning far greater shares of the world economy and its population. In particular, at certain levels of high-end warming, large areas of the planet would progressively begin to exceed the thermal maximum at which human beings are able to survive outdoors.[18] The possibilities of very rapid climate change are not implausible or ruled out by climate change models, especially as the planet warms beyond the 2 degrees Celsius temperature threshold

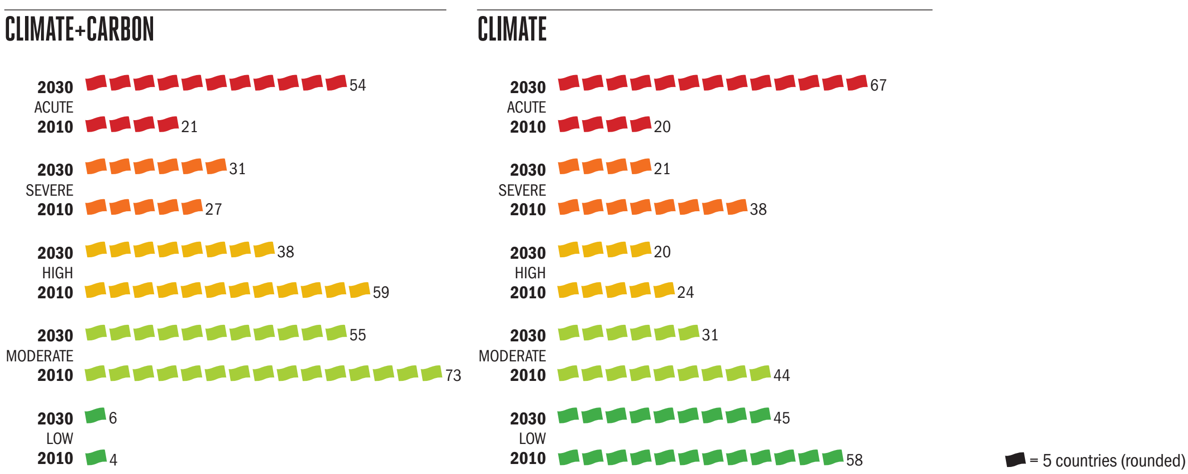
ultimately, economic advantages of aiming for a highest-action scenario, this report's findings imply that the highest action targets would reap the most benefits for the world. Therefore, the highest-action scenario is recommended to policy makers as the preferred target for enhancing and safeguarding global prosperity. Mainstream economic modelling shows that this transition is technologically and economically feasible but that action is needed now to get onto this pathway.[5] International cooperation will clearly be central to ensuring that the costs of the transition are maintained at the lowest most efficient level and that the transition yields the highest co-benefits.[6]

[1] See: Edenhofer et al., 2010; IPCC, 2012a
[2] Weitzman, 2007; Hare in Mastny, 2009
[3] For example: Hope, 2006; Stern, 2006
[4] Pope et al., 2010
[5] For an overview of some leading mitigation scenarios, see: Edenhofer et al., 2010; UNEP, 2011; IPCC, 2012a
[6] For example the economic benefits of cross-border emission reduction cooperation: De Cian and Tavoni, 2010

the international community has set for itself.[19] Of particular long-term concern are 1500 gigatonnes of CO_2 ($GtCO_2$) of methane stored in frozen sediments in the East-Siberian Sea at depths of less than 40 to 50 metres.[20] This represents three times the amount of CO_2 that could be released over much of this century if the 2 degrees target is to be kept.[21] As the Arctic sea warms due to climate change, these sediments are thawing and methane is already being visibly released at rates that currently exceed the total amount of methane emitted through natural processes over the entirety of the world's oceans.[22] While all policy pathways for reducing emissions have similar net benefits in economic terms, the highest-action route would clearly reap the greatest human, societal, economic and environmental benefits, since it would ensure the greatest chances of avoiding climate-triggered catastrophe and would minimize the human, social and environmental impacts of a hotter planet. Therefore, the cold calculus of a hot planet implies the most ambitious action on climate change is the savviest choice both in monetary, humanitarian and environmental terms. The highest-action approach is the pathway that the analysis in this report most supports.

The world risks carbon lock-in due to high-intensity carbon infrastructure plans still moving forward in the near term, so the shift in focus to a low-carbon transition should likely occur prior to 2017 and continue aggressively thereafter.[23] Several major economies will need to adjust and enact important domestic policy and legislative initiatives in order to make this a reality. Whatever the case, action on climate change that seeks out international partnership is most likely to further lessen the costs of a low-carbon transition and expand the benefits of this transition for all concerned. This report documents in part the potential benefits of avoided impacts of climate change in addition to the potential co-benefits of emission reductions that are targeted at key economic, health and environmental concerns.[24]

[1] Hansen et al., 2005
[2] Kjellstrom et al., 2009a; McSweeney et al., 2012
[3] ILO LABORSTA, 2012
[4] Storm and Naastepad, 2009; Wacker et al., 2006; Restuccia, et al., 2004; Storm and Naastepad, 2009; McMillan and Rodrik, 2012
[5] Kjellstrom et al., 2009a-b
[6] UN, 2012
[7] Ashdown et al., 2011
[8] Parry et al., 2009; EACC, 2010
[9] Cheung et al., 2010
[10] Puigdefaabregas, 1998
[11] US EIA, 2011
[12] Edenhofer et al., 2010; IPCC, 2012b
[13] Chen and Ravallion, 2012
[14] World Population Prospects/UN DESA, 2011
[15] OECD, 2012; IMF WEO, 2012; World Population Prospects/UN DESA, 2011
[16] Pope et al., 2010
[17] UNFCCC, 2009
[18] Sherwood and Huber, 2010
[19] Wietzman, 2007
[20] Shakhova et al., 2008
[21] Meinshausen et al., 2009
[22] Shakhova et al., 2008 and 2010
[23] IAE, 2011; UNEP, 2011
[24] De Cian and Tavoni, 2010



SUMMARY OF ECONOMIC IMPACT

			NET 2030	NET 2010	LOSSES 2010	GAINS 2010	2010 Developing Country Low Emitters	2010 Developing Country High Emitters	2010 Developed	2010 Other Industrialized	2030 Developing Country Low Emitters	2030 Developing Country High Emitters	2030 Developed	2030 Other Industrialized
CLIMATE	Environmental disasters	DROUGHT	18	4	4	*	*	2	1	*	4	11	3	1
		FLOODS & LANDSLIDES	94	10	10	*	2	6	1	*	21	66	5	3
		STORMS	100	15	15	*	2	3	7	*	16	64	20	*
		WILDFIRES	*	*	*	*	*	*	*	*	*	*	*	*
		TOTAL	**213**	**29**	**29**	*****	**5**	**14**	**10**	**1**	**40**	**142**	**28**	**4**
	Habitat change	BIODIVERSITY	389	78	78	*	8	26	36	9	56	299	80	54
		DESERTIFICATION	20	4	5	*	*	*	2	1	5	4	6	6
		HEATING & COOLING	-77	-33	5	-38	1	2	24	-8	30	7	-65	-49
		LABOUR PRODUCTIVITY	2,400	311	314	-3	135	162	16	-1	1,035	1,364	49	-12
		PERMAFROST	153	31	31	*	1	10	3	17	5	68	5	75
		SEA-LEVEL RISE	526	86	86	*	23	42	15	5	166	310	29	22
		WATER	13	14	44	-30	3	-3	13	7	-21	45	39	39
		TOTAL	**3,461**	**491**	**563**	**-71**	**166**	**235**	**60**	**30**	**1,276**	**1,908**	**144**	**135**
	Health impact	**TOTAL**	**106**	**23**	**23**	*****	**17**	**5**	*****	**0.5**	**84**	**21**	*****	**1**
	Industry stress	AGRICULTURE	367	50	51	*	27	17	3	2	208	144	8	10
		FISHERIES	168	13	16	-3	7	7	1	-1	97	80	-3	-6
		FORESTRY	44	6	7	-1	*	4	*	*	9	34	1	1
		HYDRO ENERGY	-24	-4	*	-4	*	-3	*	*	3	-20	-1	*
		TOURISM	*	*	5	-5	2	*	-1	*	19	-16	-2	-1
		TRANSPORT	7	1	1	*	*	*	1	*	*	1	6	*
		TOTAL	**565**	**66**	**80**	**-13**	**37**	**25**	**2**	**2**	**329**	**223**	**8**	**5**
TOTAL GLOBAL RESULTS			**4,345**	**609**	**695**	**-84**	**225**	**279**	**72**	**33**	**1,730**	**2,294**	**179**	**144**
CARBON	Environmental disasters	OIL SANDS	24	7	7	*	*	*	7	*	2	1	20	0.5
		OIL SPILLS	38	13	13	*	1	6	6	0.5	3	24	9	2
		TOTAL	**61**	**20**	**20**	*****	**1**	**6**	**13**	**0.5**	**5**	**25**	**29**	**3**
	Habitat change	BIODIVERSITY	1,734	291	291	*	32	128	114	17	236	1,034	349	115
		CORROSION	5	1.5	1.5	*	*	0.5	0.5	*	1	4	0.5	0.5
		WATER	10	4	4	*	*	*	3	1	*	2	4	4
		TOTAL	**1,749**	**296**	**296**	*****	**32**	**129**	**117**	**18**	**238**	**1,038**	**353**	**120**
	Health impact	**TOTAL**	**630**	**172**	**172**	*****	**74**	**67**	**21**	**10**	**226**	**341**	**37**	**26**
	Industry stress	AGRICULTURE	-171	15	17	-2	1	2	9	4	-58	-121	4	4
		FISHERIES	77	9	9	*	1	7	0.5	*	5	70	2	0.5
		FORESTRY	83	28	28	*	3	9	14	1	13	48	18	4
		TOTAL	**-11**	**52**	**54**	**-2**	**4**	**18**	**24**	**5**	**-40**	**-3**	**24**	**8**
TOTAL GLOBAL RESULTS			**2,429**	**540**	**542**	*****	**112**	**220**	**174**	**34**	**429**	**1,401**	**444**	**156**

* Less than one billion dollars

Billions of dollars (2010 PPP) non-discounted. Totals do not correspond exactly due to rounding.

Environmental disasters | Habitat change | Health impact | Industry stress

Developing Country Low Emitters | Developing Country High Emitters | Developed | Other Industrialized

Exhibit 10

Concerned Health Professionals of NY

PSR PHYSICIANS FOR SOCIAL RESPONSIBILITY

Compendium of Scientific, Medical, and Media Findings Demonstrating Risks and Harms of Fracking (Unconventional Gas and Oil Extraction)

Fifth Edition

March 2018

Fracking industry site near Greers Ferry Lake in Quitman, Arkansas in the Fayetteville Shale region. ©2014 Julie Dermansky

The Compendium of Scientific, Medical, and Media Findings Demonstrating Risks and Harms of Fracking (the Compendium) is a fully referenced compilation of the 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 four 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, which was funded by the Heinrich Böll Foundation and launched in Mexico City in May 2016. 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

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.

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.

Contents

About this Report

The Compendium is organized to be accessible to public officials, researchers, journalists, and the public at large. 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 which is housed on its website (https://www.psehealthyenergy.org/our-work/shale-gas-research-library/).

For this fifth edition of the Compendium, as before, we collected and compiled findings from three sources: articles from peer-reviewed medical or 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 PSE Healthy Energy database. We included review articles when such reviews revealed new understanding of the evidence. Our entries briefly describe studies that document 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 studies and investigations referenced in the dated entries catalogued in Compilation of Studies & Findings are current through December 2017. The footnoted citations here in the front matter represent studies and articles that are not referenced in the Compendium itself or which appeared as we go to press in March 2018.

Within the compiled entries, we have also provided references to articles appearing in the popular press, when available, that describe the findings of the corresponding peer-reviewed study. For this purpose, we sought out articles in the popular literature that expertly and plainly reported on studies that were highly technical, especially if those articles 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 to lay readers. Acronyms are spelled out the first time they appear in each section.

News articles appearing as individual entries signify investigative reports by journalists conducting original research. While advocacy organizations have compiled many useful reports on the impacts of fracking, these, with few exceptions, do not appear in our Compendium unless they provide otherwise inaccessible data. We also excluded papers that focused purely on methodologies or instrumentation. For some sources, cross-referenced footnotes are provided, as when wide-ranging government reports or peer-reviewed papers straddled two or more topics.

In our review of the data, seventeen compelling themes emerged; these serve as the organizational structure of the Compendium. Readers will notice the ongoing upsurge in reported problems and health impacts, 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.

The Compendium focuses on topics most closely related to the public health and safety impacts of unconventional gas and oil drilling and fracking. Additional risks and harms arise from associated infrastructure and industrial activities that necessarily accompany drilling and fracking operations. A detailed accounting of all these ancillary impacts is beyond the scope of this document. Nevertheless, we include in this edition a section on risks from fracking infrastructure that focuses on compressor stations, pipelines, silica sand mining operations, natural gas storage facilities, and, for the first time, the manufacture and transportation of liquefied natural gas (LNG).

Many other relevant concerns—such as oil trains, ethylene cracking facilities, natural gas power plants, and use of fracked gas as a feedstock in petrochemical manufacturing—are not included here. We hope to take up these issues in future editions. 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 gasses, chemicals, or pumps to extract natural gas).

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.

The Compendium is generally a volunteer project and has no dedicated funding; it was written utilizing the experience and expertise of numerous health professionals and scientists who have been involved in this issue for years.

We thank our external readers for their comments and suggestions: Casey Crandall; Barbara Gottlieb; Robert Gould, MD; Jake Hayes, MA; Douglas Hendren, MD; Lee Ann Hill, MPH; Robert Howarth, PhD; Anthony Ingraffea, PhD, PE; Adam Law, MD; Ryan Miller; Pouné Saberi, MD, MPH; Todd L. Sack, MD; Seth Shonkoff, PhD, MPH.

We welcome your feedback and comments.

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Foreword to the Fifth Edition

The Compendium in Historical Context

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. This updated version included dozens of new studies that further explicated the recurrent problems, data gaps, and ongoing uncertainties that natural gas and oil extraction via hydraulic fracturing brings with it.

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. This 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 largely aligned with our own:

> [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. (See footnote 463.)

The third edition of the Compendium, released in October 2015 and compiled as a joint effort with Physicians for Social Responsibility, included more than 100 new peer-reviewed studies as well as the results of four substantive, multi-volume government reports on the impacts of fracking. One, from the U.S. Environmental Protection Agency (EPA), focused on water. Two from the state of California examined a wide array of impacts. And, from New York, the Department of Environmental Conservation's final environmental impact statement and attendant Findings Statement—which, together, implemented New York's statewide ban—incorporated the earlier health review into a larger analysis of the impacts of fracking. 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…. (See footnote 333.)

In December 2015, this third edition became the basis of invited testimony at several 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 less than 2^{o} Celsius. As such, the treaty articulates a new vision for energy by compelling nations to monitor their greenhouse gas emissions and set increasingly ambitious targets and timetables to reduce them. The United States ratified the Paris Agreement on September 2, 2016.

The Compendium's fourth edition was released in November 2016, just as the landmark Paris Agreement went into force and just as several new studies conclusively demonstrated that expansion of shale and oil gas 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 own pledge under the Paris Agreement, namely, to reduce greenhouse gas emissions 26-28 percent by 2025, as compared to 2005 levels. (See footnotes 712, 713.)

Studies published in 2016 further indicated that methane leaks from U.S. oil and gas operations were significantly higher than previously estimated, as were U.S. methane emissions overall, which increased by more than 30 percent over a twelve year period. Most of this excess methane, which is responsible for 30-60 percent of the recent upsurge of global atmospheric methane, represents leaks from U.S. gas and oil operations. (See footnotes 714-716, 724, 733, 734.)

This fifth edition is being launched in a time of deep environmental retrenchment by the United States government, with aggressive rollbacks of federal regulatory protections, sidelining of environmental scientists, and government denial of the scientific consensus on climate change. The current administration has announced a new era of "energy dominance" based on surging domestic production—and export—of oil and natural gas, much of it extracted via fracking. References to climate change have, in some cases, been removed altogether from U.S. government websites, and greenhouse gas emissions must no longer be included in National Environment Policy Act reviews.

On June 1, 2017, the White House announced its intent to withdraw from the Paris Climate Agreement and oppose the Green Climate Fund, a financial mechanism that helps developing nations fund investments that lower their dependence on fossil fuels. These changes have taken place even as the American Meteorological Society released a major report that identified climate change as a necessary condition for several recent extreme weather events[1] and even as the Fourth National Climate Assessment—a quadrennial report compiled by 13 federal agencies—confirmed that human activities, especially emissions of carbon dioxide and methane, are the dominant cause for ongoing global warming:

> It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century. For the warming over the last century, there is no convincing alternative explanation supported by the extent of the observational evidence. . . . Human emissions of carbon dioxide (CO_2), methane (CH_4), and other greenhouse gases now overwhelm the influence of natural drivers on the external forcing of Earth's climate.[2]

[1] Herring, S. C., Christidis, N., Hoell, A., Kossin, J. P., Schreck III, C. J., & Stott, P. A. (2017). Explaining extreme events of 2016 from a climate perspective. *Bulletin of the American Meteorological Society*, *99*(1), S1–S157. Retrieved from http://www.ametsoc.net/eee/2016/2016_bams_eee_low_res.pdf

[2] U.S. Global Change Research Program. (2017). *Climate science special report: Fourth National Climate Assessment*, *Volume I.* doi: 10.7930/J0964J6

The many federal environmental rules rolled back in the United States in 2017 include those that govern drilling and fracking operations. A 2016 rule that would have increased the royalties that gas and oil companies must pay to drill on public lands was repealed. The Bureau of Land Management's Waste Prevention Rule, which requires companies drilling on public and tribal lands to reduce methane leaks and cut back on flaring and venting, was suspended. In April, the EPA canceled its Oil and Gas Methane Information Collection Request (ICR), which asked operators of existing oil and gas facilities to identify and report methane leaks. In 2016, the ICR had been the agency's first step toward regulating methane leaks from existing oil and gas sites.

Similarly, in June, the EPA delayed implementation of the Oil and Gas 111b Methane Rule, which limits methane emissions from new oil and gas drilling sites. After the D.C. Circuit Court vacated that decision, Congress defunded the rule. In October, the EPA recommended the total repeal of the Clean Power Plan, which calls for a 32 percent decrease in carbon emissions from power plants by 2030 and creates incentives for states to invest in renewable energy. In December, the U.S. Department of the Interior rescinded a 2015 rule that would have regulated fracking on public lands by requiring disclosure of chemicals in fracking fluid and tightening standards for well construction and wastewater disposal. Also in 2017, parts of the Arctic National Wildlife Refuge were opened to oil and gas drilling, and the White House revoked policies that had prevented the construction of the Dakota Access Pipeline, which now carries fracked oil from the Bakken Shale basin to an oil storage hub in Illinois.[3, 4] In January 2018, the U.S. Department of the Interior directed its field officers to expedite the sale of federal leases to the oil and gas industry by dismantling environmental protections for public lands.[5, 6] Plans for many recent federal environmental repeals are being contested in the courts.[7]

Expanding Knowledge Base

Even as we compiled entries for this fifth edition, the authors of the Compendium continued to see evidence of, and appreciate, the rapid expanse of our knowledge base. The Compendium exists within a moving stream of data. As is revealed in the Repository for Oil and Gas Energy Research, the database of literature maintained by PSE Healthy Energy, the number of peer-

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[3] Harvard University Environmental Law Program. Environmental Regulation Rollback Tracker. http://environment.law.harvard.edu/policy-initiative/regulatory-rollback-tracker/

[4] Mooney, C. (2017, December 29). To round out a year of rollbacks, the Trump administration just repealed key regulations on fracking. *The Washington Post.* Retrieved from 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

[5] U.S. Department of the Interior, Bureau of Land Management. (2018, January 31). Updating oil and gas leasing reforms - land use planning and lease parcel reviews. IM 2018-034. Retrieved from https://www.blm.gov/policy/im-2018-034

[6] Fears, D. (2018, February 1). Trump administration tears down regulations to speed drilling on public land. *The Washington Post.* Retrieved from https://www.washingtonpost.com/news/energy-environment/wp/2018/02/01/trump-administration-tears-down-regulations-to-speed-drilling-on-public-land/?utm_term=.efb30819a90c

[7] Groom, N. (2018, January 24). California to sue Trump administration for repeal of fracking rules. *Reuters.* Retrieved from https://www.reuters.com/article/us-usa-california-fracking/california-to-sue-trump-administration-for-repeal-of-fracking-rules-idUSKBN1FD2QS

reviewed publications relevant to assessing the environmental, socioeconomic, and public health impacts of shale gas development doubled between 2011 and 2012 and then doubled again between 2012 and 2013.[8] More than 90 percent of these publications have been published since January 2013, with nearly one-quarter of the now more than 1,300 available studies published in 2017 alone.[9]

The available peer-reviewed literature reveals both potential and actual harms. Specifically, as demonstrated by PSE's statistical analysis of the body of scientific literature available from 2009 to 2015, 69 percent of original research studies on water quality found potential for, or actual evidence of, water contamination; 87 percent of original research studies on air quality found significant air pollutant emissions; and 84 percent of original research studies on human health risks found signs of harm or indication of potential harm.[10]

Timeline of Bans and Moratoria

As a response to the proliferating evidence of the risks and harms of fracking—augmented by increasing concern about the many remaining uncertainties—various countries, states, and municipalities have instituted bans and moratoria.

France banned fracking in July 2011 and Bulgaria in January 2012. The state of Vermont banned fracking in May 2012.

Following New York's ban in December 2014, Scotland became the first country in Great Britain to impose a formal moratorium on fracking in January 2015, after an expert panel concluded that more study of fracking's risks was needed. (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 more difficult Scotland's goal of meeting its climate targets on greenhouse gas emissions.[11, 12]) Scotland's moratorium became an effective ban when it was extended "indefinitely" in October 2017.

[8] PSE Healthy Energy (2016, April 20). The science on shale gas development infographic. Retrieved from http://www.psehealthyenergy.org/data/PSE_FrackingStudy_Summary_Infographic_4-20-2016_00.jpg
[9] PSE Healthy Energy. Repository for Oil and Gas Research (ROGER). https://www.psehealthyenergy.org/our-work/shale-gas-research-library/
[10] Hays, J., & Shonkoff, S. B. C. (2016). Toward an understanding of the environmental and public health impacts of shale gas development: An analysis of the peer-reviewed scientific literature, 2009-2015. *PLOS One, 11*(4), e0154164. doi: 10.1371/journal.pone.0154164
[11] Health Protection Scotland. (2016, November). *A health impact assessment of unconventional oil and gas in Scotland*, vol. 1. Retrieved from http://www.hps.scot.nhs.uk/resourcedocument.aspx?resourceid=3102
[12] Committee on Climate Change. (2016, August). *Scottish unconventional oil and gas: Compatibility with Scottish greenhouse gas emissions targets*. Retrieved from http://www.gov.scot/Resource/0050/00509324.pdf

In February 2015 the government of Wales declared a moratorium on fracking "until it is proven safe." The Canadian province of New Brunswick declared a moratorium for similar reasons in March 2015.

In July 2015, the Dutch government banned all shale gas fracking until 2020 on the grounds that "research shows that there is uncertainty" about impacts.

In September 2015, Northern Ireland and the Spanish region of Castile La Mancha both effectively banned fracking via strategic planning policies.

In a December 2015 vote in favor of a report, *Towards a European Energy Union*, the plenary of the European Parliament affirmed the incompatibility of shale gas extraction via hydraulic fracturing with the European Union's commitment to 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."[13]

In Florida, 85 municipalities have either banned fracking outright or passed resolutions opposing it. In 2016, a bill that would have pre-empted local bans and opened the state to fracking was voted down in a Florida legislative committee.

Also, in 2016, New Brunswick extended its moratorium on fracking "indefinitely," citing unresolved problems with the disposal of fracking wastewater, and in the Canadian province of Newfoundland and Labrador, where a moratorium had been in place since 2013, a government-appointed panel recommended that fracking remain "paused," citing data gaps and unresolved questions about the underlying geology.

In June 2016, Germany adopted a moratorium on "unconventional fracking" until 2021 but will permit exploratory drilling research projects.

Also in 2016, California's Butte and Alameda counties banned fracking, along with Monterey County, which also banned all new oil drilling. (Santa Cruz, San Benito, and Mendocino counties banned fracking in 2014.)

In August 2016, the Australian state of Victoria declared a permanent ban on fracking on the grounds that the risks outweighed any potential benefits.

In September 2016, a California judge, arguing that the agency had failed to consider the dangers of fracking, struck down a bid by the U.S. Bureau of Land Management 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.

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

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[13] Committee on Industry, Research and Energy. (2015, November 24). *Report on Towards a European Energy Union*, A8-0341/2015. Retrieved from http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//TEXT+REPORT+A8-2015-0341+0+DOC+XML+V0//EN

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

Many more bans, moratoria, and restrictions were enacted or proposed in 2017. 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, Entre Rio 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. In October, as the moratorium on fracking in Scotland was extended indefinitely, Canada's Prince Edward Island included a prohibition on fracking as part of its Water Act. According to campaigners, Albania also enacted a national ban on fracking in 2017 but these reports are, as of this writing, unconfirmed by official sources.

In December 2017, Australia's North Territory government decided to delay a decision on whether or not to extend or lift its own moratorium on fracking after a draft final report identified multiple risks to water, land, tourism, and indigenous culture.

As we go to press in early 2018, the Delaware River Basin Commission (DRBC)—which consists of governors from the four states of New York, New Jersey, Pennsylvania, and Delaware together with the U.S. Army Corps of Engineers—has released a proposed rule to ban fracking in the Delaware River watershed on the grounds that fracking exposes its waters to "significant, immediate, and long-term risks" and has set a schedule for public hearings and comments. As currently drafted, the rule has two loopholes: it does not ban the importation of wastewater from fracking operations located outside the basin, nor does it prohibit water withdrawals from the Delaware River and its tributaries for export and use in such operations.[14, 15] The longest free-flowing river in the Northeast, the Delaware River provides drinking water to more than 15 million people (approximately 5 percent of the U.S population). About one-third of the river system flows through shale formations. A de facto moratorium on fracking in the Delaware River Basin has been in place since 2010.

In Connecticut, where no fracking takes place, ordinances prohibiting the storage or use of imported fracking waste have been passed by 34 municipalities, with more public hearings scheduled for early 2018. Vermont has banned the importation of fracking waste into the state.

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[14] Delaware River Basin Commission. (2017, November 30). Proposed new 18 CFR part 440—hydraulic fracturing in shale formations. Retrieved from http://www.nj.gov/drbc/library/documents/HydraulicFracturing/18CFR440_HydraulicFracturing_draft-for-comment_113017.pdf

[15] Hurdle, J. (2017, November 30). Fracking ban proposed for Delaware River basin; 'significant risks' cited. *StateImpact Pennsylvania.* Retrieved from https://stateimpact.npr.org/pennsylvania/2017/11/30/fracking-ban-proposed-for-delaware-river-basin-significant-risks-cited/

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 have been overturned. In May 2016, the Colorado Supreme Court struck down local fracking bans in the cities of Fort Collins and Longmont. In June 2015, citing concerns about noise impacts and the industrialization of rural landscape, the county of Lancashire in northwest England halted plans for a major British fracking operation; years previously, two wells—the first and only pair ever drilled in Lancashire—had suffered well integrity failures and caused earthquakes. However, in 2016, the national government overturned Lancashire's ban, and drilling began in October 2017 despite widespread, ongoing public opposition. Similarly, a fracking ban passed by the city of Denton, Texas in November 2014 was invalidated in June 2015 by a state law, pushed by the oil and gas industry, that prohibits Texas municipalities from passing local bans.

Introduction to Fracking

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

Fracking fluid consists of fresh water to which is added a sequence of chemicals that include biocides, friction-reducers, 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 but also naturally occurring substances carried up from the shale zone, which often include brine, heavy metals, and radioactive elements.

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 in landfills.

As fracking operations in the United States have increased in frequency, size, and intensity, and as the transport of extracted materials has expanded, a significant body of evidence has emerged to demonstrate that these activities are dangerous to people and their communities in ways that are difficult—and may prove impossible—to mitigate. Risks include adverse impacts on water, air, agriculture, public health and safety, property values, climate stability, and economic vitality, as well as earthquakes.

Researching these complex, large-scale industrialized activities—and the ancillary infrastructure that supports them—takes time and has been hindered by institutional secrecy. Nonetheless, research is gradually catching up to the last decade's surge in fracking from shale. A growing body of peer-reviewed studies, accident reports, and investigative articles has detailed specific, quantifiable evidence of harm and has revealed fundamental problems with the entire life cycle of operations associated with unconventional drilling, fracking, and fracked-gas infrastructure. Industry studies, as well as independent analyses, indicate inherent engineering problems including uncontrolled and unpredictable fracturing, induced seismicity, extensive methane leakage, and well casing and cement failures that cannot be prevented with currently available materials and technologies.

Fracking-related problems also originate from sources independent of engineering. These include habitat destruction; inadequate solutions for wastewater disposal; the presence of abandoned wells or vertical fault lines that can serve as pathways for fluid migration into aquifers; and standard operational industry norms (venting, flaring, blowdowns) that contribute to methane releases and air pollution.

Earlier scientific predictions and anecdotal evidence are now bolstered by extensive empirical data, confirming that the public health risks from unconventional gas and oil extraction are real, the range of adverse environmental impacts wide, and the negative economic consequences considerable. Our examination of the peer-reviewed medical and public health literature uncovered no evidence that fracking can be practiced in a manner that does not threaten human health.

Despite this emerging body of knowledge, industry secrecy, and government actions and inaction continue to thwart scientific inquiry, 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 illness. As a result, no quantitative and comprehensive inventory of human hazards yet exists.

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. As documented in a 2016 study by a Harvard University team, rates of withheld information and claims of trade secrecy have increased since FracFocus was first launched in 2011. (See footnotes 1082, 1083.)

The incomplete picture created by lack of transparency not withstanding, the evidence to date indicates that fracking operations pose severe threats to health, both from water contamination and from air pollution. 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 187,570 disposal wells across the country that accept oil and gas waste. (See footnote 542.) All of that two billion daily gallons of fluid is toxic, and it passes through our nation's groundwater aquifers on its way to the deep geological strata below where it demonstrably raises the risk for earthquakes. 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 79-81.)

About one-third of the natural gas inventory in the United States is used to generate electricity, and, enabled by fracking, natural gas has, as of 2016, exceeded coal as the nation's leading source of electricity.[16] With hydraulically fractured wells now producing more than two-thirds of U.S. natural gas and half of U.S. crude oil, fracking's "unconventional" techniques can no longer be considered atypical nor can the question of their public health risks be considered inconsequential.[17, 18]

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,[19] as is the upward buckling of Earth's surface that is caused by the high-pressure injection of fracking waste water into disposal wells.[20]

The dramatic increase in fracking over the last decade in the United States has pushed oil and gas extraction operations into heavily populated areas. At least six percent of the population—17.6 million Americans—now 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.[21, 22] About 8.6 million people are served by a drinking water source that is located within a mile from an unconventional well. (See footnote 156.) Understanding the potential for exposure and accompanying adverse impacts is a public health necessity.

[16] Magill, B. (2016, May 6). Fracking hits milestone as natural gas use rises in U.S. *Climate Central*. Retrieved from http://www.climatecentral.org/news/fracking-milestone-as-natural-gas-use-rises-20330

[17] U.S. Energy Information Administration. (2016, May 5). Hydraulically fractured wells provide two-thirds of U.S. natural gas production. *Today in Energy.* Retrieved from https://www.eia.gov/todayinenergy/detail.php?id=26112

[18] U.S. Energy Information Administration. (2016, March 15). Hydraulic fracturing accounts for about half of current U.S. crude oil production. *Today in Energy*. Retrieved from https://www.eia.gov/todayinenergy/detail.php?id=26112

[19] NASA Earth Observatory. (2016, March 23). Shale revolution: As clear as night and day. Retrieved from http://earthobservatory.nasa.gov/IOTD/view.php?id=87725&src=eoa-iotd

[20] Coglan, A. (2016, September 22). You can see fracking's impact on Earth's surface from space. *New Scientist.* Retrieved from https://www.newscientist.com/article/2106886-you-can-see-frackings-impact-on-earths-surface-from-space/

[21] Czolowski, E. D., Santoro, R. L., Srebotnjak, T., & Shonkoff, S. B. C. (2017). Toward consistent methodology to quantify populations in proximity to oil and gas development: A national spatial analysis and review. *Environmental Health Perspectives*, *125*(8). doi: 10.1289/EHP1535

[22] Konkel, L. (2017). In the neighborhood of 18 million: Estimating how many people live near oil and gas wells. *Environmental Health Perspectives*, *125*(8). doi: 10.1289/EHP2553

Emerging Trends

1) Growing evidence shows that regulations are simply not capable of preventing harm.

Studies reveal inherent problems in the natural gas extraction process, such as well integrity failures caused by aging or the pressures of fracking itself, and in the waste disposal process. These issues can lead to water contamination, air pollution with carcinogens and other toxic chemicals, earthquakes, and a range of 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 continue to proliferate, creating burgeoning cumulative impacts, and the size of individual wells keep 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, can now easily reach 10 to 20 million gallons per well.

The injection of extreme volumes of fluids creates significant deformations in the shale that 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 fresh water aquifers. Such pressure bulbs may mobilize contaminants left over from previous drilling and mining activities. (See footnotes 224, 225.) No set of regulations can obviate these potential impacts to groundwater. Similarly, no set of regulations can eliminate earthquake risks. (See footnote 527.)

The state of California determined that fracking can have "significant and unavoidable" impacts on air quality, including driving pollutants above levels that violate air quality standards. (See footnote 72.) Similarly, in northeastern Colorado, ambient levels of atmospheric hydrocarbons continued to increase even with tighter emission standards. (See footnote 85.)

Well sites leak far more methane and toxic vapors than previously understood, and they continue to leak long after they are decommissioned. Abandoned wells are a significant source of methane leakage into the atmosphere, and, based on findings from New York and Pennsylvania, may exceed cumulative total leakage from oil and gas wells currently in production. Plugging abandoned wells does not always reduce methane emissions, and cement plugs themselves deteriorate over time. Further, many abandoned wells are unmapped and their locations unknown. No state or federal agency routinely monitors methane leakage from abandoned wells. (See footnotes 619, 624.)

Leakage rates among active wells are 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 2016 survey of 8,000 wells using helicopters and infrared cameras. Further, much of this leakage is 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. (See footnotes 729, 730.)

2) Fracking and the disposal of fracking waste threaten drinking water.

Cases of drinking water sources contaminated by drilling and fracking activities, or by associated waste disposal, are now proven. EPA's assessment of fracking's impacts on drinking water resources confirmed specific instances of water contamination caused by drilling and fracking-related activities and identified the various pathways by which this contamination has occurred: spills; discharge of fracking waste into rivers and streams; and underground migration of chemicals, including gas, into drinking water wells.

Independently, 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. 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. In California, state regulators admitted that they had mistakenly allowed oil companies to inject drilling wastewater into aquifers containing clean, potable water. (See footnotes 206, 210, 214.) A 2017 study found that fracking wastewater discharged into rivers and streams through treatment plants created dozens of brominated and iodinated disinfection byproducts that are particularly toxic and "raise concerns regarding human health." (See footnote 141.)

As we go to press in early 2018, researchers reported on the discovery of opportunistic, pathogenic bacteria in fracking-impacted water wells in Texas and raised questions about fracking's effects on the microbial ecology of aquifers.[23] 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.[24] In Arkansas, researchers found that water withdrawals for fracking operations can deplete streams, threaten drinking water supplies, damage aquatic life, and impact recreation.[25, 26]

3) Drilling and fracking contribute to toxic air pollution and smog (ground-level ozone) at levels known to have health impacts.

Volatile organic compounds from drilling and fracking operations, together with nitrogen oxides, are responsible for 17 percent of locally produced ozone in Colorado's heavily drilled Front

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[23] Hildenbrand, Z., Santos, I., & Schug, K. (2018, January 9). Detecting harmful pathogens in water: Characterizing the link between fracking and water safety. *Science Trends.* https://sciencetrends.com/detecting-harmful-pathogens-water-characterizing-link-fracking-water-safety/

[24] Niedbala, B. (2018, January 16). W. Va. company fined $1.7 million for violations at 14 well sites in Greene County. *Observer-Reporter.* Retrieved from https://observer-reporter.com/news/localnews/w-va-company-fined-million-for-violations-at-well-sites/article_cc1ce344-faec-11e7-84ca-076df3832f29.html

[25] Entrekin, S., Trainor, A., Saiers, J., Patterson, L., Maloney, K., Fargione, J., . . .Ryan, J. N. (2018). Water stress from high-volume hydraulic fracturing potentially threatens aquatic biodiversity and ecosystem services in Arkansas, United States. *Environmental Science & Technology.* Advance online publication. doi: 10.1021/acs.est.7b03304.

[26] American Chemical Society. (2018, January 31). Potential impact of hydraulic fracturing on streams, downstream recreation, drinking water. *ScienceDaily*. Retrieved from https://www.sciencedaily.com/releases/2018/01/180131095656.htm

Range. (See footnote 59.) Colorado has exceeded federal ozone limits for the past decade, a period that corresponds to a boom in oil and gas drilling (See footnote 57.) Living near drilling and fracking operations significantly increases asthma attacks for residents of Pennsylvania, with those living near active gas wells 1.5-4 times more likely to suffer from asthma attacks than those living farther away, with the closest group having the highest risk. (See footnotes 444, 445.)

The New York State Department of Environmental Conservation determined that fracking could increase ozone levels in downwind areas of the state, potentially impacting the ability to maintain air quality that meets ozone standards. (See footnote 333.) 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 71, 72.) This increased air pollution and smog formation poses 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.

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 reverses a previous, decades-long decline; if this rate continues, U.S. ethane levels are expected to hit 1970s levels in about three years. Ethane is a potent precursor to ground-level ozone (See footnote 56, 61-63.) Emissions from drill site flaring operations also contribute to ozone creation and include several carcinogens, including benzene and formaldehyde. In 2016, the EPA acknowledged that it had dramatically underestimated health-damaging air pollutants from flaring operations. (See footnotes 55, 56.) 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, which is more than double the expected value. (See footnote 51.)

4) Public health problems associated with drilling and fracking include poor birth outcomes, reproductive and respiratory impacts, cancer risks, and occupational health and safety problems.

Studies of mothers living near oil and gas extraction operations consistently find impairments to infant health, including elevated risks for low birth weight and preterm birth. A 2017 study that examined birth certificates for all 1.1 million infants born in Pennsylvania found poorer indicators of infant health and significantly lower birth weights among babies born to mothers living near fracking sites. A 2015 Pennsylvania study found a 40 percent increase in the risk of preterm birth among infants born to mothers who lived nearby active drilling and fracking sites. A 2014 Colorado study found elevated incidence of neural tube defects and congenital heart defects. New studies in Texas and Colorado likewise found associations with infant deaths, high-risk pregnancies, and low birth weight. A 2017 pilot study in British Columbia found elevated levels of muconic acid—a marker of benzene exposure—in the urine of pregnant women living near fracking sites. (See footnotes 434, 436, 450, 472.)

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. (See footnotes 450, 1075, 1080, 1081.)

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 may be released into air and water from fracking operations. Of these, 20 are linked to leukemia or lymphoma. (See footnotes 441, 1063.)

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. 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 442.)

Among workers, risks include both accidents and toxic exposures. On-the-job fatalities from accidents in the oil and gas industry are four to seven times the national average, with contract workers at the highest risk. Occupational safety standards designed to minimize "the consequences of catastrophic releases of toxic, reactive, flammable, or explosive chemicals" in workplaces do not apply to the oil and gas industry due to legal exemptions.[27] 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 has accompanied the fracking boom in West Virginia. On January 22, 2018, a natural gas rig exploded in southeastern Oklahoma, killing five workers. As we go to press, the U.S. Chemical Safety Board has begun a full investigation into this fatal explosion, in which the well's blowout preventer failed, leading to an uncontrolled release of natural gas during a pause in the drilling process.[28] Between 2011 and 2016, at least 60 workers at oil and gas drilling sites in Oklahoma were killed on the job.

A new study from the University of Tennessee found that workers are exposed to hazardous and carcinogenic air pollutants from multiple sources, with chemical storage tanks presenting the highest cancer risk. 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 377, 415, 423.)

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[27] Jones, C. (2018, February 3). OSHA standards moot in Quinton rig explosion because of exemption for oil-and-gas industry. *Tulsa World*. Retrieved from http://www.tulsaworld.com/news/state/osha-standards-moot-in-quinton-rig-explosion-because-of-exemption/article_162d0efa-7860-5f4b-b982-ebdeb142c075.html

[28] U.S. Chemical Safety Board. (2018, January 31). *Update on the CSB's ongoing investigation into the fatal gas well explosion in Oklahoma.* [Press release]. Retrieved from http://www.csb.gov/update-on-the-csbs-ongoing-investigation-into-the-fatal-gas-well-explosion-in-oklahoma-/

5) Natural gas is a threat to the climate.

From a greenhouse gas perspective, natural gas is not a cleaner fuel than coal and may be worse. Methane is a much more potent greenhouse gas than formerly appreciated. The Intergovernmental Panel on Climate Change estimates that, over a 20-year time frame, methane can, pound for pound, trap 86 times more heat than carbon dioxide and is 34 times more potent a greenhouse gas over a 100 year period. (See footnote 780.) Further, real-world methane leakage rates from drilling and fracking operations greatly exceed earlier estimates. 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 contribute 71-85 percent of the methane emissions in the region.

Much of the methane emitted from drilling and fracking activities and associated infrastructure originates not from accidental leaks but from losses that are inherent to the design of the machinery or to normal operating use and are, therefore, not possible to mitigate. (See footnotes 848-850.) Inactive, abandoned wells are also significant methane emitters. 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.

Methane leakage from oil and gas operations makes the urgent task of limiting global warming to below levels called for in the Paris Climate Agreement increasingly difficult. Recent evidence shows that methane emissions from the fossil fuel industry are 20-60 percent higher than previously thought, and that a surge in atmospheric methane levels are now driving climate impacts of rising human-caused greenhouse gases. As we go to press, a major new study led by NASA researchers has confirmed that the sharp uptick in global methane since 2006 is largely attributable to fossil fuel sources.[29] Many climate researchers now call for a renewed emphasis on reducing methane emissions to combat climate change. (See footnotes 710, 711.)

6) Earthquakes are a proven consequence of drilling and fracking-related activities in many locations.

Several major studies, using different methodologies, have confirmed a causal link between the injection of fracking wastewater in disposal wells and earthquake swarms. Using structural geology analysis, a 2017 study of the Fort Worth basin showed that a recent swarm of small earthquakes in northern Texas was originating in long-inactive, ancient fault lines in deep formations where fracking wastewater is being injected; human activity is the only plausible explanation. (See footnote 499.) Another recent 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

[29] Worden, J. R., Bloom, A. A., Pandey, S., Jiang, Z., Worden, H. M., Walker, T. W., . . . Rockmann, R. (2017). Reduced biomass burning emissions reconcile conflicting estimates of the post-2006 atmospheric methane budget. *Nature Communications, 2227.* doi: 10.1038/s41467-017-02246-0.

immediately following a rapid increase in fracking wastewater injection nearby. (See footnotes 522, 523.)

The number of earthquakes of magnitude 3.0 or higher has skyrocketed in Oklahoma since the advent of the fracking boom, with fewer than two per year before 2009 and more than 900 in 2015 alone. The 5.8 earthquake that struck near Pawnee on September 3, 2016 was the strongest in Oklahoma's history. Felt by residents in five states, the Pawnee quake prompted a state of emergency declaration and an order from state regulators to shut down 67 wastewater disposal wells in the area. (See footnote 520, 521.) 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 worked to solve the problem. (See footnote 519.) On November 6, 2013, a magnitude 5.0 earthquake struck Cushing, Oklahoma near the site of the nation's largest oil hub, where 60 million barrels of crude oil were stored. The quake injured one, damaged more than 40 buildings, closed a school, and triggered evacuations. Oil infrastructure was not damaged. Recent evidence shows that the process of fracking itself can trigger small earthquakes, as several confirmed cases demonstrate.

7) Fracking infrastructure poses serious potential 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. Pipelines themselves can freeze, corrode, break, and leak. Between January 2010 and November 2017, according to data from the federal Pipeline and Hazardous Materials Safety Administration, pipeline incidents killed 100 people, injured 500, prompted the evacuation of thousands, and leaked more than 17 billion cubic feet of methane.[30] Low-pressure flow lines alone are responsible for more than 7,000 spills and leaks since 2009. (See footnote 821.)

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.

Fracking infrastructure in the United States also includes 400 underground gas storage facilities in 31 states, with scant federal oversight and aging equipment. The four-month leak at the nation's fifth largest facility, Aliso Canyon in southern California, between October 2015 and February 2016 resulted in exposures of large suburban population to an uncontrollable array of chemicals. With a release of nearly 100,000 metric tons of methane, it became the worst methane leak in U.S. history. (See footnote 873.)

[30] Thompson, J. (2017, November 29). A map of $1.1 billion in natural gas pipeline leaks. *High Country News*. Retrieved from http://www.hcn.org/issues/49.22/infographic-a-map-of-leaking-natural-gas-pipelines-across-the-nation

A major pollution source even before the blow-out, Aliso Canyon 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 8,000 households were evacuated and relocated, with residents reporting multiple symptoms, including headaches, nosebleeds, eye irritation, and nausea. Contaminated house dust became a contentious issue. Measurement of airborne contaminants during the leak was intermittent and contained major gaps. The Aliso Canyon facility reopened on July 31, 2017. Four months later, a gasket failure led to a methane leak, and at least 15 residents noticed foul odors. As of early 2018, more than two years after the original blow-out, the Aliso Canyon facility operates at only 28 percent of its storage capacity, and the community still awaits the initiation of a mandated health study, which, independent researchers say, must include attention to sub-chronic, cumulative exposures.

As we go to press, the California Council of Science and Technology has released a 910-page report analyzing the safety risks of all 14 facilities in the state that store gas in depleted oil fields. Among its findings: gas companies do not disclose the chemicals they are pumping underground; state regulators lack necessary information to assess risks; and many wells servicing the storage fields are 60 to 90 years old with no regulatory limit to the age of the well.[31]

LNG facilities—and the pipelines, coastal terminals, and ships that service them—are a growing component of fracking infrastructure as the shale gas boom has allowed the United States to seek long-term supply contracts for natural gas exports. In July 2017, the United Kingdom received its first delivery of LNG from the Sabine Pass export terminal in Louisiana. The Cove Point LNG export facility in Maryland is, as we go to press, preparing its first shipments of Marcellus Shale gas, destined for Japan and India. Five other U.S. LNG export terminals are in the planning stage.

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 to keep the methane chilled during transport. Explosive and with the ability to flash-freeze human flesh, LNG creates acute security and public safety risks. Its greenhouse gas emissions are 30 percent higher than conventional natural gas due to refrigeration, venting, leaks, and flaring, used to control pressure during regasification. 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 910-26.)

8) Drilling and fracking activities can bring naturally occurring radioactive materials to the surface.

Exposure to increased radiation levels from fracking materials is a risk for both workers and residents. A study demonstrated that radon levels in Pennsylvania homes rose since the advent of the fracking boom, and buildings in heavily drilled areas had significantly higher radon readings

[31] Birkholzer, J., & Long, J. C. S., Report Steering Committee Co-Chairs, California Council of Science and Technology. (2018, January 18). *Long-term viability of underground natural gas storage in California: an independent review of scientific and technical information.* Retrieved from http://ccst.us/publications/2018/Full%20Technical%20Report%20v2.pdf

than areas without well pads—a discrepancy that did not exist before 2004. University of Iowa researchers documented a variety of radioactive substances including radium, thorium, and uranium in fracking wastewater and determined that their radioactivity increased over time; they warned that radioactive decay products can potentially contaminate recreational, agricultural, and residential areas.

The New York State Department of Environmental Conservation's "Findings Statement" noted that naturally occurring radioactive materials (NORM) are brought to the surface "in the cuttings, flowback water and production brine. . . . [T]he build-up of NORM in pipes and equipment has the potential to cause a significant adverse impact because it could expose workers handling pipes, for cleaning or maintenance, to increased radiation levels." (See footnotes 333, 347-371.)

9) The risks posed by fracking in California are unique.

Hydraulic fracturing in California is practiced differently than in other states, making its risks different, as well. 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. California is the only state that allows fracking waste to be held in unlined, open pits, which creates risks for both air and groundwater contamination. As of January 2017, 1,000 such pits were operational, with 400 lacking required state permits. The vast majority are located in Kern County.[32] In 2014, the discovery that companies had, for years, been wrongly allowed to inject fracking waste directly into California's freshwater aquifers led to the closing of 175 disposal wells. Impacts on drinking water are unknown. (See footnotes 144, 145.)

Most new fracking operations in California take 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. And although fracking requires considerably less water per well in California, it takes place disproportionately in areas of severe water shortages and can compete with municipal and agricultural needs for freshwater.

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 675-677.)

These factors project fracking's impacts onto geographically distant populations, especially in cases when wastewater is diverted for use in crop irrigation and livestock watering. Food is a troubling possible exposure route to fracking chemicals, in part because so little is known about

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[32] California Water Boards. (2017, January 31). *Produced water pond status report.* Retrieved from https://www.waterboards.ca.gov/water_issues/programs/groundwater/sb4/docs/pond_rpt_0117_fnl.pdf

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 secret. 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 670.)

The other area in California where fracking is concentrated, the Los Angeles Basin, is located directly under one of the most populous cities in the world. At least 1.7 million people in Los Angeles live or work within one mile of an active oil or gas well. California does not currently limit how close to residences or schools drilling and fracking activities can be conducted. A new 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 150.)

10) Fracking in Florida presents many unknowns.

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.[33] 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.

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

[33] Could leftover wastewater from balky oil well end up a health hazard? (2015, January 1). *Naples Daily News.* Retrieved from http://archive.naplesnews.com/news/local/could-leftover-wastewater-from-balky-oil-well-end-up-a-health-hazard-ep-853723380-335781721.html/

underground terrain of the Floridan Aquifer resembles a vast, brittle, sponge partly covered with sand and clay. Springs and sinkholes are common.[34, 35]

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.[36]

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 645-647.)

As of early 2018, 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."[37] 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.[38]

11) The economic instabilities of fracking further exacerbate public health risks.

Real-life challenges to the industry's arguments that fracking is good business are increasingly apparent. Independent economic analyses show that the promise of local job creation has been

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[34] Johnson, R. H., & Bush, P. W. (2013, September 4). *Summary of the hydrology of the Floridan Aquifer System in Florida and in parts of Georgia, South Carolina, and Alabama.* U.S. Geological Survey Professional Paper 1403-A. Retrieved from https://sofia.usgs.gov/publications/papers/pp1403a/
[35] Tihansky, A. B., & Knochenmus, L. A. (2001, February 13). *Karst features and hydrogeology in west-central Florida. U.S.* Geological Survey Water-Resources Investigations Report 01-4011. Retrieved from https://water.usgs.gov/ogw/karst/kigconference/abt_karstfeatures.htm
[36] Miami-Dade County Wellfield Technical Work Group. (2017, July 31). *Final Report.* Retrieved from http://ecmrer.miamidade.gov:8080/reports/WellfieldTechnicalWorkgroupReportJuly2017.pdf
[37] Russo, R., & Screaton, E. (2016, May 9). Should Florida 'frack' its limestone for oil and gas? Two geophysicists weigh in. *University of Florida News.* Retrieved from http://news.ufl.edu/articles/2016/05/should-florida-frack-its-limestone-for-oil-and-gas-two-geophysicists-weigh-in.php
[38] Lustgarten, A. (2012, June 21). Injection wells: the poison beneath us. *ProPublica.* Retrieved from: https://www.propublica.org/article/injection-wells-the-poison-beneath-us

greatly exaggerated, with many jobs going to out-of-area workers. Reports show that oil and gas jobs will increasingly be lost to automation. 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, and strains on law enforcement and municipal services. School districts report increased stress. Economic analyses have found that drilling and fracking threaten property values and can diminish tax revenues for local governments. Additionally, drilling and fracking pose an inherent conflict with mortgages and property insurance due to the hazardous materials used and the associated risks.

Throughout its history, the tempo of drilling and fracking operations in the United States has fluctuated markedly. Since 2014, when oil prices dropped precipitously, oil and gas operations have struggled to make a profit. In March 2016, the number of working gas rigs fell to its lowest level since record-keeping began in 1987. Downturns, however, do not necessarily translate into less risk and exposure to harm for those living in frontline communities. In spite of fewer drill rigs, injections of fracking wastewater *increased* in Ohio by 15 percent in 2015, likely because operators began drilling wells with longer lateral pipelines to access more gas or oil per well, generating more waste even as the pace of drilling slowed. (See footnote 188.) Indeed, according to data provided to investors, the average amount of water used to frack a single well has more than doubled between 2013 and 2016 due to longer laterals and more intensive fracking.

Further, orphaned wells left behind by industry during energy price downturns or after bankruptcy are poorly monitored and, as conduits for gas and fluid leakage, become health and safety threats. Some have exploded.[39]

In 2017, the rate of active shale gas drilling in the United States was, once again, on the upswing.[40] In spite of this uptick, output from two major basins has fallen, likely because easy-to-access gas has already been extracted.[41] Because the production of individual wells declines precipitously over the course of a few years, operators must continue drilling new wells at a rapid pace to maintain output.

The unstable economic fundamentals of the industry as a whole have multiple consequences for public health and safety as cumulative impacts mount from wells, both old and new. Weak prices, difficulty generating positive cash flow, short-lived well production, and falling output have led drilling companies to reduce the value of their assets by billions of dollars. Concerns arise that these losses will lead to large-scale firings, cutbacks in safety measures, and landscapes pock-marked by hastily abandoned wells in need of remediation and long-term monitoring.

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[39] Zoffos, J. (2018, January 16). 'Orphaned' oil and gas wells are on the rise." *High Country News*. Retrieved from http://www.hcn.org/articles/energy-industry-orphaned-oil-and-gas-wells-are-on-the-rise

[40] Sisk, A. (2017, December 29). Pennsylvania's gas fields ramp up for more drilling in 2018. *StateImpact Pennsylvania.* Retrieved from https://stateimpact.npr.org/pennsylvania/2017/12/29/pennsylvanias-gas-fields-ramp-up-for-more-drilling-in-2018/

[41] Montgomery, J. B., & O'Sullivan, F. M. (2017). Spatial variability of tight oil well productivity and the impact of technology. *Applied Energy, 195*, 344-55. doi: 10.1016/j.apenergy.2017.03.038.

12) Fracking raises issues of environmental justice.

Inequalities in opportunities to participate in environmental decision-making and uneven impacts of environmental hazards along racial and socioeconomic lines are signature issues of environmental justice. Although not yet fully characterized, emerging evidence reveals that, in several regions where fracking is practiced, well pads and associated infrastructure are disproportionately sited in non-white and low-income communities.

A pattern of racially biased permitting was documented in the heavily fracked Eagle Ford area of southern Texas where 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.[42] 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.[43] Another recent study looked at economic disparities in the intensely drilled northern Texas city of Denton and found that those benefiting most from Denton's mineral wealth tended to live 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."[44]

Poor communities of color are disproportionately affected by drilling activities in California. 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.[45] 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.[46] 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.[47]

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[42] Johnston, J. E., Werder, E., & Sebastian, D. (2016). Wastewater disposal wells, fracking, and environmental justice in southern Texas. *American Journal of Public Health, 106*(3). doi: 10.2105/AJPH.2015.303000

[43] Bienkowski, B. (2016, February 3). Poor, minorities carry the burden of frack waste in South Texas. *Environmental Health News.* Retrieved from http://www.environmentalhealthnews.org/ehs/news/2016/feb/fracking-waste-eagle-ford-texas-hispanic-environmental-justice

[44] Fry, M., Briggle, A., & Kincaid, J. (2015). Fracking and environmental (in)justice in a Texas city. *Ecological Economics, 117*. doi: 10.1016/j.ecolecon.2015.06.012

[45] Reyes, E. A. (2015, November 6). Environmental advocates sue L.A., accusing it of "rubber stamping" oil drilling plans. *Los Angeles Times*. Retrieved from http://www.latimes.com/local/lanow/la-me-ln-lawsuit-oil-drilling-20151106-story.html

[46] Fleming, J. C., & Kim, C. (2017, December 13). *Danger next door: The top 12 air toxics used for neighborhood oil drilling in Los Angeles.* Retrieved from http://www.biologicaldiversity.org/publications/papers/DangerNextDoor.pdf

[47] PSE Healthy Energy. (2017, April). *Natural gas power plants in California's disadvantaged communities.* Retrieved from https://www.psehealthyenergy.org/wp-content/uploads/2017/04/CA.EJ_.Gas_.Plants.pdf

Another study found a higher concentration of drilling and fracking operations in impoverished communities throughout the state of Pennsylvania as well as in localized areas of West Virginia, but it did not find differences with respect to race. "The results demonstrate that the environmental injustice occurs in areas with unconventional wells in Pennsylvania with respect to the poor population."[48] 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.[49]

13) Health professionals are increasingly calling for bans or moratoria on fracking, based on a range of potential health hazards and as reviews of the data confirm evidence for harm.

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 856.) 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 855.)

In May 2016, Physicians for Social Responsibility called for a ban on fracking. (See footnote 1079.) 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 1077.) 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 can be adequately determined through a comprehensive Health Impact Assessment. (See footnote 1074.) The group noted that the operation of natural gas facilities risks human exposures to toxic, cancer-causing, and radioactive pollution due to the presence of naturally co-occurring contaminants, toxic additives to the hydraulic fracturing process used to produce much of the country's natural gas supply, 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 1071, 1072). In February 2017, health officials in Los Angeles called for a comprehensive health study in the aftermath of the massive methane leak in Aliso Canyon. (See footnote 1068.)

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[48] Ogneva-Himmelberger, Y., & Huang, L. (2015). Spatial distribution of unconventional gas wells and human populations in the Marcellus Shale in the United States: vulnerability analysis. *Applied Geography, 60*, 165-174. doi: 10.1016/j.apgeog.2015.03.011

[49] Frazier, R. (2016, June 30). Is fracking an environmental justice issue? *The Allegheny Front.* Retrieved from https://www.alleghenyfront.org/is-fracking-an-environmental-justice-issue/

Concerned Health Professionals of New York, which provided scientific and medical guidance for the successful effort to ban fracking in New York State, has inspired affiliations of like-minded public health scientists and health care providers that have been advocating for moratoria or bans on fracking in various other regions. These include Concerned Health Professionals of Maryland, Concerned Health Professionals of Ireland, and Concerned Health Professionals of Neuquén, Argentina. Other U.S. medical groups calling for bans or moratoria include Chesapeake PSR and the Alliance of Nurses for Healthy Environments.

Compilation of Studies & Findings

Air pollution

Air pollution associated with fracking is a grave concern with a range of impacts. Researchers have documented dozens of air pollutants from drilling and fracking operations that pose serious health hazards. 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 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. Exposure to emissions from natural gas flares and diesel exhaust from the 4,000-6,000 truck trips per well pad are also respiratory health risks for those living near drilling operations. Evidence implicates the U.S. shale gas boom in the recent global spike in atmospheric ethane. 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. The accelerating pace of drilling and fracking activities and the current policy plan to reverse course on proposed regulations to reduce methane emissions are likely to exacerbate the air pollution problems that fracking creates, along with attendant health risks.

- 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."[50]

[50] Schade, G. W. (2017, November 2). How has the US fracking boom affected air pollution in shale areas? *The Conversation.* Retrieved from https://theconversation.com/how-has-the-us-fracking-boom-affected-air-pollution-in-shale-areas-66190

- 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 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.[51]

- 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.[52, 53]

- 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."[54]

- 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.[55, 56]

- 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

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[51] Gvakharia, A., Kort, E. A., Brandt, A., Peischl, J., Ryerson, T. B., Schwarz, J. P., … Sweeney, C. (2017). Methane, black carbon, and ethane emissions from natural gas flares in the Bakken Shale, North Dakota. *Environmental Science & Technology, 51*(9), 5317-5325. doi: 10.1021/acs.est.6b05183

[52] McCawley, M. A. (2017). Does increased traffic flow around unconventional resource development activities represent the major respiratory hazard to neighboring communities?: Knowns and unknowns. *Current Opinion in Pulmonary Medicine, 23*(2), 161-166. doi: 10.1097/MCP.0000000000000361

[53] Frazier, R. (2017, June 16). On health effects, blame the trucks, not the fracking? *Allegheny Front.* Retrieved from https://www.alleghenyfront.org/on-health-effects-blame-the-trucks-not-the-fracking/

[54] Robbins, J. (2016, October 16). In new ozone alert, a warning of harm to plants and to people. *Yale Environment 360.* Retrieved from http://e360.yale.edu/feature/ground_level_ozone_harming_plants_humans/3044/

[55] United States District Court for the District of Columbia. (2016, October 16). Air Alliance Houston, et al. v. Gina McCarthy, Administrator, United States Environmental Protection Agency. Consent decree. Case 1:16-cv01998. Retrieved from https://www.documentcloud.org/documents/3127584-Consent-Decree-on-Flares.html

[56] Hasemyer, D. (2016, October 13). EPA agrees that its emissions estimates from flaring may be flawed. *InsideClimate News*. Retrieved from https://insideclimatenews.org/news/12102016/epa-natural-gas-oil-drilling-flaring-emissions-estimates-flawed-fracking

standards. Colorado has exceeded federal ozone limits for the past decade, a period that corresponds to a statewide boom in oil and gas drilling.[57]

- 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."[58]

- 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.[59] 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.[60]

- 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.[61] 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.[62] 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

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[57] Boiko-Weyrauch, A. (2016, October 5). Ozone, asthma and the oil and gas connection. *Inside Energy.* Retrieved from http://insideenergy.org/2016/10/05/ozone-asthma-and-the-oil-and-gas-connection/

[58] Marrero, J. E., Townsend-Small, A., Lyon, D. R., Tsai, T. R., Meinardi, S., & Blake, D. R. (2016). Estimating emissions of toxic hydrocarbons from natural gas production sites in the Barnett Shale Region of Northern Texas. *Environmental Science & Technology, 50*(19), 10756-10764. doi: 10.1021/acs.est.6b02827

[59] McDuffie, E.E., Edwards, P.M., Gilman, J.B., Lerner, B.M., Dubé, W.P., Trainer, M., . . . Brown, S.S. (2016). Influence of oil and gas emissions on summertime ozone in the Colorado Northern Front Range. *Journal of Geophysical Research: Atmospheres*. doi: 10.1002/2016JD025265

[60] University of Colorado at Boulder. (2016, August 8). Accounting for ozone: Study first to quantify impact of oil and gas emissions on Denver's ozone problem. *ScienceDaily*. Retrieved from https://www.sciencedaily.com/releases/2016/08/160808123832.htm

[61] Helmig, D., Rossabi, S., Hueber, J. Tans, P., Montzka, S. A., Masarie, K., . . . Pozzer. A. (2016). Reversal of global atmospheric ethane and propane trends largely due to US oil and natural gas production. *Nature Geoscience, 9,* 490–495. doi: 10.1038/ngeo2721

[62] Helmig, D. & Scott, J. (2016, June 13). Global ethane concentrations rising again, says study. *News Center University of Colorado Boulder.* Retrieved from http://www.colorado.edu/news/releases/2016/06/13/global-ethane-concentrations-rising-again-says-study

exceedances in the Uintah Basin, Utah, and Upper Green River Basin, Wyoming, [oil and 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."[63] (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."[64]

- 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.[65] "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.[66] 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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[63] Hakola, H. & Hellén, H. (2016). The return of ethane. *Nature Geoscience, 9,* 475-476. doi: 10.1038/ngeo2736
[64] Webb, E., Hays, J., Dyrszka, L., Rodriguez, B., Cox, C., Huffling, K., & Bushkin-Bedient, S. (2016). 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*(2), 225-243. doi: 10.1515/reveh-2014-0070
[65] Kort, E. A., Smith, M. L., Murray, L. T., Gvakharia, A. Brandt, A. R., Peischl, J., . . .Travis, K. (2016). Fugitive emissions from the Bakken shale illustrate role of shale production in global ethane shift. *Geophysical Research Letters, 43,* 4617–4623. doi: 10.1002/2016GL068703
[66] Moore, C. S., & Human K. (2016, April 26). One oil field a key culprit in global ethane gas increase. *Michigan News.* Retrieved from http://ns.umich.edu/new/multimedia/videos/23735-one-oil-field-a-key-culprit-in-global-ethane-gas-increase

- April 5, 2016 – Helicopter-based infrared camera surveys of more than 8,000 oil and gas wells in seven U.S. regions found that well pads emit considerably more methane and VOCs than captured by earlier inventories. Moreover, these emissions were widely and unpredictably variable from site to site and from well to well. Over 90 percent of total airborne emissions from well pads originated with vents and hatches on aboveground storage tanks.[67] The inability to predict which well sites were "superemitters" (meaning that they leaked into the air more than 200 cubic feet of methane and VOCs per hour) implies that continuous, site-specific monitoring is required to regulate methane leaks from drilling and fracking operations. In a comment about the findings to *InsideClimate News*, Cornell University engineer Anthony Ingraffea, who was not an author of the paper, said, "It makes regulation very difficult. If you have all these possible sites where you can have leaks, you can never have enough inspectors with all the right equipment being in all the right places at all the right times. It's too complex a system."[68]

- 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.[69]

- 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,

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[67] Lyon, D. R., Alvarez, R. G., Zavala-Araiza, D., Brandt, A. R., Jackson, R. B., & Hamburg, S. P. (2016). Aerial surveys of elevated hydrocarbon emissions from oil and gas production sites. Environmental Science & Technology 50(9). doi: 10.1021/acs.est.6b00705

[68] McKenna, P. (2016, April 8). Researchers find no shortcuts for spotting wells that leak the most methane. *InsideClimate News*. Retrieved from: https://insideclimatenews.org/news/07042016/big-methane-leaks-superemitters-oil-gas-production-climate-change-edf

[69] Haley, M., McCawley, M., Epstein, A. C., Arrington, B., & Bjerke, E. F. (2016). Adequacy of current state setbacks for directional high-volume hydraulic fracturing in the Marcellus, Barnett, and Niobrara Shale plays. *Environmental Health Perspectives.* Advance online publication. doi: 10.1289/ehp.1510547

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.[70]

- 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 stimulation emissions directly, and it is not possible to determine well stimulation emissions from current inventory methods."[71]

- 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.[72, 73]

- 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

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[70] Evans, R. B., Prezant, D., & Huang, Y. C. (2015). Hydraulic fracturing (fracking) and the Clean Air Act. *Chest, 148*(2), 298-300. doi: 10.1378/chest.14-2582
[71] Brandt, A., Millstein, D., Jin, L., & Englander, J. (2015, July 9). Air quality impacts from well stimulation. In: California Council on Science and Technology, *An Independent Scientific Assessment of Well Stimulation in California*, volume 2, chapter 3. Retrieved from http://ccst.us/publications/2015/vol-II-chapter-3.pdf
[72] California Department of Conservation, Division of Oil, Gas, and Geothermal Resources (2015, July 1). *Analysis of Oil and Gas Well Stimulation Treatments in California, Volume II.* Retrieved from http://www.conservation.ca.gov/dog/SB4DEIR/Pages/SB4_DEIR_TOC.aspx
[73] Cart. J. (2015, July 1). State issues toughest-in-the-nation fracking rules. *Los Angeles Times.* Retrieved from http://www.latimes.com/local/lanow/la-me-ln-state-issues-fracking-rules-20150701-story.html

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."[74]

- 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.[75] The extent to which the results can be generalized to the Marcellus basin as a whole, the authors emphasized, remains uncertain.[76]

- 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 U.S. Environmental Protection Agency (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.[77] "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."[78]

- 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

[74] McCawley, M. (2015). Air contaminants associated with potential respiratory effects from unconventional resource development activities. *Seminars in Respiratory and Critical Care Medicine 36*(3), 379-387. doi: 10.1055/s-0035-1549453
[75] Phillips, S. (2015, May 19). Study: Lower than expected air pollutants detected at Marcellus drilling sites. *State Impact Pennsylvania.* Retrieved from https://stateimpact.npr.org/pennsylvania/2015/05/19/study-lower-than-expected-air-pollutants-from-gas-drilling-sites/
[76] Goetz, J. D., Floerchinger, C., Fortner E. C., Wormhoudt, J., Massoli, P., Knighton, W. B., . . . DeCarlo, P.F. (2015). Atmospheric emission characterization of Marcellus Shale natural gas development sites. *Environmental Science & Technology, 49,* 7012-20. doi: 10.1021/acs.est.5b00452
[77] Bienkowski, B. (2015, April 15). Scientists warn of hormone impacts from benzene, xylene, other common solvents. *Environmental Health News.* Retrieved from http://www.environmentalhealthnews.org/ehs/news/2015/apr/endocrine-disruption-hormones-benzene-solvents
[78] Bolden, A. L., Kwiatkowski, C. F., & Colborn, T. (2015). New look at BTEX: Are ambient levels a problem? *Environmental Science & Technology, 49,* 5261-76. doi: 10.1021/es505316f

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 fracking operations.[79, 80] 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.[81]

- 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.[82] 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.[83]

- 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.[84]

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[79] Vinciguerra, T. Yao, S., Dadzie, J., Chittmans, A., Deskins, T., Ehrman, S., & Dickerson, R. R. (2015). Regional air quality impacts of hydraulic fracturing and shale natural gas activities: evidence from ambient VOC observations. *Atmospheric Environment, 110,* 144-50. doi: 10.1016/j.atmosenv.2015.03.056

[80] Valentine, K. (2015, April 30). Fracking wells could pollute the air hundreds of miles away. *ClimateProgress*. Retrieved from http://thinkprogress.org/climate/2015/04/30/3653252/fracking-air-pollution-downwind/

[81] Levine, F. & Tune, L. (2015, April 30). Emissions from natural gas wells may travel far downwind. *University of Maryland: UMD Right Now.* Retrieved from http://www.umdrightnow.umd.edu/news/emissions-natural-gas-wells-may-travel-far-downwind

[82] Pacsi, A. P., Kimura, Y., McGaughey, G., McDonald-Buller, E. C., & Allen, D. T. (2015). Regional ozone impacts of increased natural gas use in the Texas power sector and development in the Eagle Ford Shale. *Environmental Science & Technology, 49,* 3966-73. doi: 10.1021/es5055012

[83] Swarthout, R. F., Russo, R.S., Zhou, Y., Miller, B.M., Mitchell, B., Horsman, E., . . . Sive, B.C. (2015). Impact of Marcellus Shale natural gas development in southwest Pennsylvania on volatile organic compound emissions and regional air quality. *Environmental Science & Technology, 49,* 3175-84. doi: 10.1021/es504315f

[84] Davis, B. (2014, November 20). TCEQ memo proves toxic chemicals are being released in the Eagle Ford Shale. *KENS 5 Eyewitness News.* Retrieved from http://www.kens5.com/story/news/investigations/i-team/2014/11/20/benzene-oil-toxic-fumes/70020596/

- 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 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.”[85]

- 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.[86] “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.”[87]

- 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.[88] The researchers plan additional monitoring and analysis.

- October 21, 2014 – Using a mobile laboratory designed by the National Oceanic and Atmospheric Administration (NOAA), a research team from the University of Colorado

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[85] Thompson C. R., Hueber J., & Helmig D. (2014). Influence of oil and gas emissions on ambient atmospheric non-methane hydrocarbons in residential areas of Northeastern Colorado. *Elementa: Science of the Anthropocene, 2*. doi: 10.12952/journal.elementa.000035

[86] Macey, G. P., Breech, R., Chernaik, M., Cox, C., Larson, D., Thomas, D., & Carpenter, D. O. (2014). Air concentrations of volatile compounds near oil and gas production: a community-based exploratory study. *Environmental Health, 13*(82). doi: 10.1186/1476-069X-13-82

[87] Neuhauser, A. (2014, October 30). Toxic chemicals, carcinogens skyrocket near fracking sites. *U.S. News and World Report*. Retrieved from http://www.usnews.com/news/articles/2014/10/30/toxic-chemicals-and-carcinogens-skyrocket-near-fracking-sites-study-says

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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). 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.[89]

- October 2, 2014 – A joint investigation by *InsideClimate 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.[90]

- 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."[91]

- 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

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[89] Warneke, C., Geiger, F., Edwards, P. M., Dube, W., Pétron, G., Kofler, J., . . . Roberts, J. M. (2014). 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,* 10977-10988. doi: 10.5194/acp-14-10977-2014

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[91] Edwards, P. M., Brown, S. S., Roberts, J. M., Ahmadov, R., Banta, R. M., deGouw, J.A., . . Zamora, R. (2014). High winter ozone pollution from carbonyl photolysis in an oil and gas basin. *Nature, 514*(7522), 351-354. doi: 10.1038/nature13767

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)."[92]

- 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 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.]"[93]

- 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.[94]

- 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.[95]

- 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."[96]

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[93] ShaleTest Environmental Testing. (2014, September). Project playground: Cleaner air for active kids. Retrieved from http://www.shaletest.org/wp-content/uploads/2014/09/ProjectPlaygoundPatagoniaReport-5-1.pdf
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[96] McMahon, J. (2014, June 26). Air pollution spikes in homes near fracking wells. *Forbes*. Retrieved from http://www.forbes.com/sites/jeffmcmahon/2014/06/26/air-pollution-spikes-in-homes-near-fracking-wells/

- May 8, 2014 – Researchers at the National Oceanic and Atmospheric Administration (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 *Denver Post* noted that Colorado's Front Range has failed to meet federal ozone air quality standards for years.[97]

- 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."[98] 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."[99]

- 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.[100]

- 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

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[97] Finley, B. (2014, May 8). Scientists flying over Colorado oil boom find worse air pollution. *The Denver Post*. Retrieved from http://www.denverpost.com/environment/ci_25719742/scientists-flying-over-colorado-oil-boom-find-worse
[98] Morris, J. (2014, April 26). Texas family plagued with ailments gets $3M in 1st-of-its-kind fracking judgment. *CNN*. Retrieved from http://www.cnn.com/2014/04/25/justice/texas-family-wins-fracking-lawsuit/
[99] Shonkoff, S. B., Hays, J., & Finkel, M. L. (2014). Environmental public health dimensions of shale and tight gas development. *Environmental Health Perspectives, 122,* 787–795. doi: 10.1289/ehp.1307866
[100] Morris, J., Song, L., & Hasemayer, D. (2014, April 11). Report: Air quality to worsen in Eagle Ford shale. *The Texas Tribune*. Retrieved from http://www.texastribune.org/2014/04/11/report-air-quality-worsen-eagle-ford-shale/

not taken into account, and local weather conditions and vulnerable populations are ignored.[101]

- 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.[102, 103]

- 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.”[104] Researchers estimated that total annual VOC emissions at the fracking sites are equivalent to those of about 100 million cars.[105]

- 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.[106]

- February 18, 2014 – An eight-month investigation by the *Weather Channel*, the *Center for Public Integrity*, and *InsideClimate News* into fracking in the Eagle Ford Shale in Texas revealed that fracking is “releasing a toxic soup of chemicals into the air.” They

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[101] Brown, D., Weinberger, B., Lewis, C., & Bonaparte, H. (2014). Understanding exposure from natural gas drilling puts current air standards to the test. *Reviews on Environmental Health, 29*(4), 277-92. doi: 10.1515/reveh-2014-0002
[102] Rawlins, R. (2013). 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*, 226-306. Retrieved from http://www.velj.org/uploads/1/2/7/0/12706894/2._rawlins_-_barnett_shale.pdf
[103] University of Texas at Austin. (2014, March 27). Air pollution and hydraulic fracturing: Better monitoring, planning and tracking of health effects needed in Texas. Retrieved from http://www.utexas.edu/news/2014/03/27/hydraulic-fracturing-texas/
[104] Helmig, D., Thompson, C. R., Evans, J., Boylan, P., Hueber, J., & Park, J. (2014). Highly elevated atmospheric levels of volatile organic compounds in the Uintah Basin, Utah [Abstract]. *Environmental Science & Technology, 48*(9), 4707-4715. doi: 10.1021/es405046r
[105] Lockwood, D. (2014, March 25). Harmful air pollutants build up near oil and gas fields. *Chemical & Engineering News*. Retrieved from http://cen.acs.org/articles/92/web/2014/03/Harmful-Air-Pollutants-Build-Near.html
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noted very poor monitoring by the state of Texas and reported on hundreds of air complaints filed relating to air pollution associated with fracking.[107]

- 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.[108]

- 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."[109]

- 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 (PAHs) at "concentrations greater than those at which prenatally exposed children in urban studies had lower developmental and IQ scores."[110]

- 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.[111]

- 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

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[107] Morris, J., Song, L., & Hasemayer, D. (2014, February 18). Fracking the Eagle Ford Shale. *The Weather Channel*. Retrieved from http://stories.weather.com/fracking

[108] Rich, A., Grover, J. P., & Sattler, M. L. (2014). 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*(1), 61-72. doi: 10.1080/10962247.2013.832713

[109] Junkins, C. (2013, December 10). Health dept. concerned about benzene emissions near local gas drilling sites. *The Intelligencer, Wheeling News-Register*. Retrieved from http://www.theintelligencer.net/page/content.detail/id/593209/Health-Dept--Concerned-About-Benzene-Emissions-Near-Local-Gas-Drilling-Sites.html?nav=510

[110] Colborn, T., Schultz, K., Herrick, L., & Kwiatkowski, C. (2014). An exploratory study of air quality near natural gas operations. *Human and Ecological Risk Assessment: An International Journal, 20*(1), 86-105. doi: 10.1080/10807039.2012.749447

[111] Wilson, S., Sumi, L., & Subra, W. (2013, September 19). Reckless endangerment while fracking the Eagle Ford shale. *Earthworks*. Retrieved from http://www.earthworksaction.org/library/detail/reckless_endangerment_in_the_eagle_ford_shale#.UkGi-4Y3uSo.

hematopoietic cancers (leukemia and non-Hodgkin's lymphoma) in men who live closer to the facilities.[112]

- 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.[113]

- 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.[114]

- 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.[115] 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.[116]

- 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.[117] 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.[118]

- December 3, 2012 – A study linked a single well pad in Colorado to more than 50 airborne chemicals, 44 of which have known health effects.[119]

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[112] Simpson, I. J., Marrero, J. E., Batterman, S. & Blake, D. R. (2013) Air quality in the Industrial Heartland of Alberta, Canada and potential impacts on human health. *Atmospheric Environment*, *81,* 702-709. doi: 10.1016/j.atmosenv.2013.09.017
[113] Grossman, D. (2013, April 29). Clean air report card: CO, WY Counties get F's due to oil and gas pollution. *Environmental Defense Fund*. Retrieved from 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
[114] Litovitz, A., Curtright, A., Abramzon, S., Burger, N., & Samaras, C. (2013). Estimation of regional air-quality damages from Marcellus Shale natural gas extraction in Pennsylvania. *Environmental Research Letters, 8*(1). doi: 10.1088/1748-9326/8/1/014017
[115] Concerned Health Professionals of NY. (2013, February 27). Letter to Governor Cuomo. Retrieved from http://concernedhealthny.org/letters-to-governor-cuomo/
[116] Campbell, J. (2013, April 17). Fracking roundup: Gas prices up; Medical society wants moratorium. *Politics on the Hudson*. Retrieved from http://polhudson.lohudblogs.com/2013/04/17/fracking-roundup-gas-prices-up-medical-society-wants-moratorium/
[117] Tollefson, J. (2013). Methane leaks erode green credentials of natural gas. *Nature*, *493*(7430), 12-12. doi: 10.1038/493012a
[118] American Lung Association. (2013). American Lung Association state of the air 2013 - Ozone pollution. Retrieved from http://www.stateoftheair.org/2013/health-risks/health-risks-ozone.html
[119] Colborn, T., Schultz, K., Herrick, L., & Kwiatkowski, C. (2014). An exploratory study of air quality near natural gas operations. *Human and Ecological Risk Assessment: An International Journal, 20*(1), 86-105. doi: 10.1080/10807039.2012.749447

- 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.[120]

- March 19, 2012 – A Colorado School of Public Health study found air pollutants near fracking sites linked to neurological and respiratory problems and cancer.[121, 122] 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."[123]

- 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.[124]

- 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.[125]

- 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…."[126]

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[120] Olaguer, E. P. (2012). The potential near-source ozone impacts of upstream oil and gas industry emissions. *Journal of the Air & Waste Management Association, 62*(8), 966-977. doi: 10.1080/10962247.2012.688923
[121] Kelly, D. (2012, March 19). Study shows air emissions near fracking sites may pose health risk. *University of Colorado Denver*. Retrieved from http://www.ucdenver.edu/about/newsroom/newsreleases/Pages/health-impacts-of-fracking-emissions.aspx
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[124] Physicians, Scientists & Engineers for Healthy Energy. (2011, December 12). Appeal to Gov. Cuomo to consider cancer risks re: High volume hydraulic fracturing for natural gas [Letter to A. Cuomo].
[125] Physicians, Scientists & Engineers for Healthy Energy. (2011, October 5). Letter to Governor Cuomo [Letter to A. Cuomo].
[126] Streater, S. (2011, April 21). Air pollution: Winter ozone problem continues to mystify regulators, industry. *E&E Publishing, LLC*. Retrieved from http://www.eenews.net/stories/1059948108

- 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.[127]

- 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.[128] Ozone is a key risk factor for asthma and other respiratory and cardiovascular illnesses.[129, 130, 131, 132]

- 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."[133, 134]

- 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.[135]

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[127] Gruver, M. (2011, March 8). Wyoming is beset by a big-city problem: Smog. *USA Today*. Retrieved from http://usatoday30.usatoday.com/money/industries/energy/2011-03-08-natural-gas-ozone-wyoming_N.htm
[128] Kemball-Cook, S., Bar-Ilan, A., Grant, J., Parker, L., Jung, J., Santamaria, W., . . . Yarwood, G. (2010). Ozone impacts of natural gas development in the Haynesville Shale. *Environmental Science & Technology, 44*(24), 9357-9363. doi: 10.1021/es1021137
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[131] Shah, A. S., Langrish, J. P., Nair, H., McAllister, D. A., Hunter, A., L., Donaldson, K., . . . Mills, N. L. (2013). Global association of air pollution and heart failure: a systematic review and meta-analysis. *The Lancet, 382*(9897), 1039-1048. doi: 10.1016/S0140-6736(13)60898-3.
[132] Myers, O., Flowers, H., Kang, H., Bedrick, E., Whorton, B., Cui, X., & Stidley, C. A. (2007). 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. Retrieved from http://www.nmenv.state.nm.us/aqb/4C/Documents/SanJuanAsthmaDocBW.pdf
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[134] Battlement Mesa HIA/EHMS. (2013, November 30). Retrieved from http://www.garfield-county.com/environmental-health/battlement-mesa-health-impact-assessment-draft2.aspx
[135] The Associated Press. (2010, January 27). Texas agency finds high benzene levels on Barnett Shale. Retrieved from http://www.nola.com/business/index.ssf/2010/01/texas_agency_finds_high_benzen.html

Water contamination

Substantial evidence shows that drilling and fracking activities, and associated wastewater disposal practices, inherently threaten groundwater and have polluted drinking water sources, as confirmed by the 2016 final report of the U.S. Environmental Protection Agency (EPA) on the impacts of fracking on the nation's drinking water. Repudiating industry claims of risk-free fracking, 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, the state has determined that more than 300 private drinking water wells have been contaminated or otherwise impacted as the result of drilling and fracking operations over an eight-year period. As determined by the U.S. Agency for Toxic Substances and Disease Registry (ATSDR), the chemical contamination of some private water wells in Dimock, Pennsylvania posed demonstrable health risks, rendering the water unsuitable for drinking.

Evidence on 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. 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. As components of the fracking waste stream, these toxic substances also 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 5 percent of all fracking waste is lost to spills, often during transport. Spills and intentional discharges of 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 and populations of sensitive fish species, such as brook trout. New studies documenting changes in the bacterial flora in groundwater following drilling and fracking operations represent an emerging area of concern.

- 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 water is pumped. In Howard County alone, water used for fracking is now believed to constitute about 20 percent of average annual water use.[136]

- 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 *InsideClimate 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."[137]

- 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."[138]

- 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

[136] Collins, C. (11 December, 2017). Big spring vs. big oil. *Texas Observer.* Retrieved from https://www.texasobserver.org/big-spring-vs-big-oil/
[137] Banerjee, N. (16 November, 2017). Industrial strength: How the U.S. government hid fracking's risks to drinking water. *InsideClimate News.* Retrieved from https://insideclimatenews.org/news/16112017/fracking-chemicals-safety-epa-health-risks-water-bush-cheney
[138] Santos, I. C., Martin, M. S., Reyes, M. L., Carlton Jr., D. D., Stigler-Granados, P., Valerio, M. A., … & Schug, K. A. (2017). Exploring the links between groundwater quality and bacterial communities near oil and gas extraction activities. *Science of the Total Environment. 618,* 165-173. doi: 10.1016/j.scitotenv.2017.10.264

alone, there were 400 cases of frack fluid from horizontal wells flooding nearby vertical wells.[139, 140]

- 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."[141]

- 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."[142, 143]

- 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

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139 Soraghan, M. (1 November, 2017). Now it's oilmen who say fracking could harm groundwater. *E&E News.* Retrieved from https://www.eenews.net/stories/1060065209

140 OEPA. (2017, September 14). Are vertical wells impacted by horizontal drilling? A study of Kingfisher County. *E&E News*. Retrieved from https://www.eenews.net/assets/2017/10/27/document_pm_07.pdf

141 Liberatore, H. K., Plewa, M. J., Wagner, E. D., VanBriesen, J. M., Burnett, D. B., Cizmas, L. H., & Richardson, S. D. (2017). Identification and comparative mammalian cell cytotoxicity of new iodo-phenolic disinfection byproducts in chloraminated oil and gas wastewaters. *Environmental Science & Technology Letters, 4*(11), 475–480. doi: 10.1021/acs.estlett.7b00468

142 Martin, M. S., Santos, I. C., Carlton Jr. D. D., Stigler-Granados, P., Hildenbrand, Z. L., & Schug, K. A. (2017). Characterization of bacterial diversity in contaminated groundwater using matrix-assisted laser desorption/ionization time-of-flight mass spectrometry. *Science of the Total Environment.* Advance online publication. doi: 10.1016/j.scitotenv.2017.10.027

143 Mosier, J. (2017, December 1). UTA research finds dangerous bacteria in groundwater near Texas gas drilling sites. *Dallas News.* Retrieved from 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."[144] An earlier investigation by KQED Science revealed that illegal wastewater wells would still be allowed to operate while the necessary paperwork was filed.[145]

- 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.[146, 147]

- May 31, 2017 – A U.S. Geological Survey (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."[148]

- 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."[149] [See also entry below for October 13, 2016.]

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[144] Sommer, L. (17 August, 2017). How much drinking water has California lost to oil industry waste? No one knows. *KQED Science.* Retrieved from https://ww2.kqed.org/science/2017/08/03/how-much-drinking-water-has-california-lost-to-oil-industry-waste-no-one-knows/
[145] Sommer, L. (17 January, 2017). California says oil companies can keep dumping wastewater during state review. *KQED Science.* Retrieved from https://ww2.kqed.org/science/2017/01/17/california-says-oil-companies-can-keep-dumping-wastewater-during-state-review/
[146] Burgos, W. D., Castillo-Meza, L., Tasker, T. L., Geeza, T. J., Drohan, P. J., Liu, X., … Warner, N. R. (2017). Watershed-scale impacts from surface water disposal of oil and gas wastewater in Western Pennsylvania. *Environmental Science & Technology, 51*(15), 8851–8860. doi: 10.1021/acs.est.7b01696
[147] Johnston, I., (2017, July 12). Fracking can contaminate rivers and lakes with radioactive material, study finds. *The Independent*. Retrieved from http://www.independent.co.uk/news/science/fracking-dangers-environment-water-damage-radiation-contamination-study-risks-a7837991.html
[148] McMahon, P., Barlow, J. R. B., Engle, M. A., Belitz, K., Ging, P. B., Hunt, A. G., … & Kresse, T. M. (2017). Methane and benzene in drinking-water wells overlying the Eagle Ford, Fayetteville, and Haynesville Shale hydrocarbon production areas. *Environmental Science & Technology, 51*(12), 6727-6734. doi: 10.1021/acs.est.7b00746
[149] Hill, E., & Ma, L. (2017). Shale gas development and drinking water quality. *American Economic Review: Papers & Proceedings, 107*(5), 522–525. doi: 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 well bore, 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."[150]

- 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.[151] 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."[152]

- 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.[153, 154]

- 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

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[150] Stringfellow, W. T., Camarillo, M. K., Domen, J. K., & Shonkoff, S. B. C. (2017) Comparison of chemical-use between hydraulic fracturing, acidizing, and routine oil and gas development. *PLoS ONE, 12*(4), e0175344. doi: 10.1371/journal.pone.0175344

[151] Harkness, J. S., Darrah, T. H., Warner, N. R., Whyte, C. J., Moore, M. T., Millot, R., … Vengosh, A. (2017). The geochemistry of naturally occurring methane and saline groundwater in an area of unconventional shale gas development. *Geochimica et Cosmochimica Acta, 208,* 302–334. doi: 10.1016/j.gca.2017.03.039

[152] Lucas, T. (2017, April 24). *West Virginia groundwater not affected by fracking, but surface water is* [Press release]. Retrieved from https://nicholas.duke.edu/about/news/west-virginia-groundwater-not-affected-fracking-surface-water

[153] Patterson, L., Konschnik, K., Wiseman, H., Fargione, J., Maloney, K. O., Kiesecker, J., … Saiers, J. E. (2017). Unconventional oil and gas spills: Risks, mitigation priorities and states reporting requirements. *Environmental Science & Technology, 51*(5), 2563–2573. doi: 10.1021/acs.est.05749

[154] Kusnetz, N. (2017, February 21). Fracking well spills poorly reported in most top-producing states, study finds. *InsideClimate News.* Retrieved from: https://insideclimatenews.org/news/21022017/fracking-spills-north-dakota-colorado

adverse effects, including alterations in liver functioning and disruption of hormonal pathways. [This study was partially funded by industry.][155]

- 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.[156, 157, 158, 159] The final EPA report detailed the problem of fracking-related drinking water contamination in three communities—Pavillion, Wyoming; Dimock, Pennsylvania; and Parker County, Texas.[160] 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."[161] [See also the entry for June 5, 2015, which describes the contents of the 2015 draft report.]

- 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

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[155] He, Y., Folkerts, E. J., Zhang, Y., Martin, J. W. Alessi, D. S., & Goss, G. G. (2017). 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*(2), 940-947. doi: 10.1021/acs.est.6b04695

[156] U.S. EPA. (2016). *Hydraulic fracturing for oil and gas: Impacts from the hydraulic fracturing water cycle on drinking water resources in the United States.* U.S. Environmental Protection Agency, Washington, DC, EPA-600-R-16-236Fa. Retrieved from https://www.epa.gov/hfstudy

[157] U.S. EPA. (2016). *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, Washington, DC, EPA-600-R-16-236Fb. Retrieved from https://www.epa.gov/hfstudy

[158] U.S. EPA. (2016). *Hydraulic fracturing for oil and gas: Impacts from the hydraulic fracturing water cycle on drinking water resources in the United States* (Executive Summary). U.S. Environmental Protection Agency, Washington, DC, EPA-600-R-16-236ES. Retrieved from https://www.epa.gov/hfstudy

[159] Tong, S., & Scheck, T. (30 November, 2016). EPA's late changes to fracking study downplay risk of drinking water pollution. *Marketplace.org.* Retrieved from https://www.marketplace.org/2016/11/29/world/epa-s-late-changes-fracking-study-portray-lower-pollution-risk

[160] U.S. Environmental Protection Agency Science Advisory Board. (2016, August 11). *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-16-005. Retrieved from https://yosemite.epa.gov/sab/sabproduct.nsf/LookupWebReportsLastMonthBOARD/BB6910FEC10C01A18525800C00647104/$File/EPA-SAB-16-005+Unsigned.pdf

[161] Scheck, T. & Tong, S. (2016, December 13). EPA reverses course, highlights fracking contamination of drinking water. *APM Reports.* Retrieved from https://www.apmreports.org/story/2016/12/13/epa-fracking-contamination-drinking-water

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.[162]

- 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.[163]

- 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.[164]

- 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."[165]

- 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. This "averting behavior" is a measure of perceived risk. In 2010, averting-behavior expenditures in the form of bottle water purchases by people living in Pennsylvania's

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[162] Konkel, L. (2016). Salting the earth: The environmental impact of oil and gas wastewater spills. *Environmental Health Perspectives, 124*(12), A230-A235. doi: 10.1289/ehp.124-A230
[163] Shrestha, N., Chilkoor, G., Wilder, J., Gadhamshetty, V., & Stone, J. J. (2016). Potential water resource impacts of hydraulic fracturing from unconventional oil production in the Bakken shale. *Water Research, 108,* 1-24. doi: 10.1016/j.watres.2016.11.006
[164] Stringfellow, W. T., Camarillo, M. K., Domen, J. K., Sandelin, W. L., Varadharajan, C., Jordan, P. D., & … Birkholzer, J. T. (2017). Identifying chemicals of concern in hydraulic fracturing fluids used for oil production *Environmental Pollution, 220,* Part A, 413-420. doi: 10.1016/j.envpol.2016.09.082
[165] Grant, C. J., Lutz, A. K., Kulig, A. D., & Stanton, M. R. (2016). Fracked ecology: Response of aquatic trophic structure and mercury biomagnification dynamics in the Marcellus Shale Formation. *Ecotoxicology, 25,* 1739–1750. doi: 10.1007/s10646-016-1717-8

shale counties totaled $19 million.[166] [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."[167]

- 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.[168, 169]

- 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."[170] Duke University geochemist Avner Vengosh, who was not an author

[166] Wrenn, D. H., Klaiber, H. A., & Jaenicke, E. C. (2016). Unconventional shale gas development, risk perceptions, and averting behavior: evidence from bottled water purchases. *Journal of the Association of Environmental and Resource Economists, 3*(4), 770-817. doi: 10.1086/688487
[167] Yost, E. E., Stanek, J., & Burgoon, L. D. (2016). 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,* 1544–1558. doi: 10.1016/j.scitotenv.2016.08.167
[168] Hildenbrand, Z. L., Carlton Jr., D. D., Meik, J. M., Taylor, J. T., Fontenot, B. E., Walton, J. L., … Schug, K. A. (2016). A reconnaissance analysis of groundwater quality in the Eagle Ford shale region reveals two distinct bromide/chloride populations. *Science of the Total Environment, 575,* 672–680. doi: 10.1016/j.scitotenv.2016.09.070
[169] Hildenbrand, Z. L., Carlton Jr., D. D., Meik, J. M., Taylor, J. T., Fontenot, B. E., Walton, J. L., … Schug, K. A. (2017). 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, 603–604,* 834-835. doi: 10.1016/j.scitotenv.2017.05.200
[170] Sherwood, O. A., Rogers, J. D., Lackey, G., Burke, T. L., Osborn, S. G. & Ryan, J. N. (2016). 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*(30). doi: 10.1073/pnas.1523267113

of the paper, commented on the study in an accompanying article in *InsideClimate 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, *InsideClimate 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.[171]

- 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.[172] 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.[173, 174]

- 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.[175] 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."[176] (This study

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[171] Banerjee, N. (2016, July 11). Colorado fracking study blames faulty wells for contamination. *InsideClimate News.* Retrieved from https://insideclimatenews.org/news/11072016/water-contamination-near-colorado-fracking-tied-well-failures

[172] U.S. Agency for Toxic Substances and Disease Registry (2016, May 24). *Health Consultation: Dimock Groundwater Site*. Retrieved from http://www.atsdr.cdc.gov/hac/pha/DimockGroundwaterSite/Dimock_Groundwater_Site_HC_05-24-2016_508.pdf

[173] Lustgarten, A. (2016, June 9). Federal report appears to undercut EPA assurances on water safety in Pennsylvania. *ProPublica.* Retrieved from https://www.propublica.org/article/federal-report-appears-to-undercut-epa-assurances-water-safety-pennsylvania

[174] U.S. Environmental Protection Agency. (2012, July 25). *EPA completes drinking water sampling in Dimock, Pa.* [Press release]. Retrieved from https://yosemite.epa.gov/opa/admpress.nsf/0/1A6E49D193E1007585257A46005B61AD

[175] Akob, D. M., Mumford, A. C., Orem, W. H., Engle, M. A., Klinges, J. G., Kent, D. B., & Cozzarelli, I. M. (2016). Wastewater disposal from unconventional oil and gas development degrades stream quality at a West Virginia injection facility. *Environmental Science and Technology, 50*(11). doi: 10.1021/acs.est.6b00428

[176] Fears, D. (2016, May 11). This mystery was solved: scientists say chemicals from fracking wastewater can taint fresh water nearby. *The Washington Post.* Retrieved from 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."[177]

- 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.[178] 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."[179]

- 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.[180, 181] (See also entry for May 9, 2016 above.)

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[177] Schladen, M. (2016, April 30). Flooding sweeps oil, chemicals into rivers. *El Paso Times.* Retrieved from http://www.elpasotimes.com/story/news/2016/04/30/flooding-sweeps-oil-chemicals-into-rivers/83671348/
[178] Lauer, N. E., Harkness, J. S., & Vengosh A. (2016). Brine spills associated with unconventional oil development in North Dakota. *Environmental Science & Technology, 50*(10). doi: 10.1021/acs.est.5b06349
[179] Nicholas School of the Environment, Duke University. (2016, April 27). *Contamination in North Dakota linked to fracking spills* [Press release]. Retrieved from https://nicholas.duke.edu/about/news/ContaminationinNDLinkedtoFrackingSpills
[180] Kassotis, C. D., Iwanowicz, L. R., Akob, D. M., Cozzarelli, I. M., Mumford, A. C., Orem, W. H., & Nagel, S. C. (2016). Endocrine disrupting activities of surface water associated with West Virginia oil and gas industry wastewater disposal site. *Science of the Total Environment 557-558.* doi: 10.1016/j.sci.tenv.2016.03.113
[181] Bienkowski, B. (2016, April 6). In W. Virginia, frack wastewater may be messing with hormones. *Environmental Health News*. Retrieved from http://www.environmentalhealthnews.org/ehs/news/2016/april/in-w.-virginia-frack-wastewater-may-be-messing-with-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.[182] 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."[183] Co-author Rob Jackson noted, "There are no rules that would stop a company from doing this anywhere else."[184]

- 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.[185,186]

- 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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[182] DiGiulio, D. C. & Jackson, R. B. (2016). 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*(8). doi: 10.1021/acs.est.5b04970

[183] Banerjee, N. (2016, March 29). Fracking study finds toxins in Wyoming town's groundwater and raises broader concerns. *InsideClimate News*. Retrieved from https://insideclimatenews.org/news/29032016/fracking-study-pavillion-wyoming-drinking-water-contamination-epa

[184] Jordan, R. (2016, March 29). Stanford researchers show fracking's impact to drinking water sources. Stanford News. Retrieved from http://news.stanford.edu/2016/03/29/pavillion-fracking-water-032916/

[185] Elsner, M. & Hoelzer, K. (2016). Quantitative survey and structural classification of hydraulic fracturing chemicals reported in unconventional gas production. *Environmental Science & Technology, 50*(7). doi:10.1021/acs.est.5b02818

[186] Phys.Org. (9 March 2016). How to get a handle on potential risks posed by fracking fluids. Retrieved from 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.[187]

- 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.[188]

- 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.[189] (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.[190] 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

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[187] Shipp, B. (2016, February 9). Drilling records suggest lax state enforcement. WFAA, Dallas. Retrieved from http://www.wfaa.com/mb/news/local/investigates/rules-ignored-water-fouled-in-barnett-shale/38337835
[188] Arenschield, L. (2016, February 8). Drillers using more water to frack Ohio shale. *The Columbus Dispatch*. Retrieved from http://www.dispatch.com/content/stories/local/2016/02/07/drillers-using-more-water-to-frack-ohio-shale.html
[189] U.S. Government Accountability Office. (2016, February). *Drinking Water: EPA Needs to Collect Information and Consistently Conduct Activities to Protect Underground Sources of Drinking Water.* GAO-16-281. Retrieved from http://gao.gov/assets/680/675439.pdf
[190] Elliot, E. G., Ettinger, A. S., Leaderer, B. P., Bracken, M. B., Deziel, N. (2016). A systematic evaluation of chemicals in hydraulic-fracturing fluids and wastewater for reproductive and developmental toxicity. Advance online publication. *Journal of Exposure Science & Environmental Epidemiology.* doi: 10.1038/jes.2015.81

monitoring drinking water in people's homes, is vital for understanding the public health impact of hydraulic fracturing."[191]

- 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.[192, 193]

- 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.[194] (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.[195]

- 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'

[191] Greenwood, M. (2016, January 6). Toxins found in fracturing fluid and wastewater, study shows. *Yale News*. Retrieved from: http://news.yale.edu/2016/01/06/toxins-found-fracking-fluids-and-wastewater-study-shows
[192] Renock, D., Landis, J. D., & Sharma, M. (2016). Reductive weathering of black shale and release of barium during hydraulic fracturing. *Applied Geochemistry, 65.* doi: 10.1016/j.apgeochem.2015.11.001
[193] Dartmouth College. (15 December 2015). Fracking plays active role in generating toxic metal wastewater, study finds. *Science Daily*. Retrieved from https://www.sciencedaily.com/releases/2015/12/151215134653.htm
[194] Storrow, B. (2015, December 6). Pavillion today an EPA in retreat, a narrow state inquiry and no answers. *Caspar Star Tribune*. Retrieved from 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
[195] Banerjee, N. (2015, November 19). EPA finding on fracking's water pollution disputed by its own scientists. *InsideClimate News*. Retrieved from 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.[196]

- 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."[197, 198]

- 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.[199]

- 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.[200]

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[196] Woodwell, C. (2016, October 19). Pa. regulators fail to protect environment during Marcellus Shale boom. *Penn Live*. Retrieved from http://www.pennlive.com/midstate/index.ssf/2015/10/state_regulators_fail_to_prote.html
[197] Drollette, B. D., Hoelzer, K., Warner, N. R., Darrah, T. H., Karatum, O., O'Connor, M. P. … Plata, D. L. (2015). 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*(43). doi: 10.1073/pnas.1511474112
[198] Drollette B. D. & Plata, D. A. (2015, October 13). Hydraulic fracturing components in Marcellus groundwater likely from surface operations, not wells. *Phys.Org*. Retrieved from http://phys.org/news/2015-10-hydraulic-fracturing-components-marcellus-groundwater.html
[199] Entrekin, S. A., Maloney, K. O., Kapo, K. E., Walters, A. W., Evan-White, M. A., & Klemow, K. M. (2015). Stream vulnerability to widespread and emergent stressors: a focus on unconventional oil and gas. *PLoS One, 10*(9). doi:10.1371/journal.pone.0137416
[200] Cart, J. (2015, July 30). Central valley wastewater disposal to continue despite contamination. *Los Angeles Times.* Retrieved from 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.[201] 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.[202]

- 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.[203] 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.[204] 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.[205] In addition, because the oil-

[201] Jordon, R. (2015, July 21). *Shallow fracking raises questions for water, new Stanford research shows.* [Press release]. Retrieved from http://news.stanford.edu/news/2015/july/fracking_water-jackson-072115.html
[202] Jackson, R. B., Lowry, E. R., Pickle, A., Kang, M., DiGiullo, D., & Zhao, K. (2015). The depths of hydraulic fracturing and accompanying water use across the United States. *Environmental Science & Technology*, *49*(15). 8969–8976. doi: 10.1021/acs.est.5b01228
[203] Shonkoff, S. B. C., Jordan, P., Hays, J., Stringfellow, W. T., Wettstein, Z. S., Harrison, R., Sandelin, W., & McKone, T. E. (2015, July 9). Volume II, 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, Sacramento, CA. Retrieved from http://ccst.us/publications/2015/vol-II-chapter-6.pdf
[204] Baker, D. R. (2015, July 16). U.S. likely to bar oil-waste dumping into 10 California aquifers. *San Francisco Chronicle.* Retrieved from http://www.sfchronicle.com/business/article/U-S-likely-to-bar-oil-waste-dumping-into-10-6389677.php
[205] Stringfellow, W. T., Cooley H., Varadharajan, C., Heberger, M., Reagan, M. T., Domen, J.K., . . . Houseworth, J. E. (2015, July 9). Volume II, Chapter 2: Impacts of well stimulation on water resources. In: *An Independent Scientific Assessment of Well Stimulation in California.* California Council on Science and Technology, Sacramento, CA. Retrieved from http://ccst.us/publications/2015/vol-II-chapter-2.pdf

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 direct contamination of groundwater by fracking, the study concluded, reflects absence of investigation rather than evidence of safety.[206]

- 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.[207]

- 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.[208] 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.[209]

- 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),

[206] Long, J. C. S, Birkholzer, J. T., & Feinstein, L. C. (2015, July 9). Summary report. In: *An Independent Scientific Assessment of Well Stimulation in California.* California Council on Science and Technology, Sacramento, CA. Retrieved from: http://ccst.us/publications/2015/2015SB4summary.pdf

[207] Gallegos, T. J., Varela, B. A., Haines, S. S., & Engle, M. A. (2015). Hydraulic fracturing water use variability in the United States and potential environmental implications. *Water Resources Research*. Accepted author manuscript. doi: 10.1002/2015WR017278

[208] Belitz, K., Fram, M. S., & Johnson, T. D. (2015). Metrics for assessing the quality of groundwater used for public supply, CA, USA: equivalent-population and area. *Environmental Science & Technology*, *9*(14), 8330–8338. doi: 10.1021/acs.est.5b00265

[209] Knickmeyer E., & Smith, S. (2015, July 15). Study finds contaminants in California public-water supplies. *Associated Press.* Retrieved from http://abcnews.go.com/Health/wireStory/study-finds-contaminants-california-public-water-supplies-32476456

detections of methanol and ethanol, and strikingly high levels of 10 different metals.[210] "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."[211]

- 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.[212] 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."[213]

- 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

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[210] Hildenbrand, Z. L., Carlton, D. D., Fontenot, B. E., Meik, J. M., Walton, J.L., Taylor, J. T., . . .Schug, K.A. (2015) A comprehensive analysis of groundwater quality in the Barnett Shale region. *Environmental Science & Technology, 49*(13), 8254-8262. doi: 10.1021/acs.est.5b01526

[211] McPhate, C. (2015, June 18). New study reveals potential contamination. *Denton Record-Chronicle*. Retrieved from http://www.dentonrc.com/local-news/local-news-headlines/20150618-new-study-reveals-potential-contamination.ece

[212] U.S. EPA. (2015). *Assessment of the potential impacts of hydraulic fracturing for oil and gas on drinking water resources* (External review draft). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-15/047, 2015. Retrieved from http://cfpub.epa.gov/ncea/hfstudy/recordisplay.cfm?deid=244651

[213] Ward Jr., K. (2015, June 7). EPA says new study doesn't show fracking is safe. *Charleston Gazette*. Retrieved from http://www.wvgazettemail.com/article/20150607/GZ01/150609432

intermediate depth fractures to the aquifer used as a potable water source."[214] In an accompanying *New York Times* story, lead author Susan Brantley described the geology 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."[215]

- 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."[216]

- 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."[217]

- 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

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[214] Llewellyn, G. T., Dorman, F., Westland, J. L., Yoxtheimer, D., Grieve, P. Sowers, T., . . . Brantley, S. L. (2015). Evaluating a groundwater supply contamination incident attributed to Marcellus Shale gas development. *Proceedings of the National Academies of Science, 112,* 6325-30. doi: 10.1073/pnas.1420279112/-/DCSupplemental
[215] St. Fleur, N. (2015, May 4). Fracking chemicals detected in Pennsylvania drinking water. *The New York Times*. Retrieved from http://www.nytimes.com/2015/05/05/science/earth/fracking-chemicals-detected-in-pennsylvania-drinking-water.html?_r=0#addendums
[216] Rogers, J. D., Burke, T. L., Osborn, S. G., & Ryan, J. N. (2015). 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*, 158-64.
[217] Johnson, E., Austin, B. J., Inlander, E., Gallipeau, C., Evans-White, M. A., & Entrekin, S. (2015). Stream macroinvertebrate communities across a gradient of natural gas development in the Fayetteville Shale. *Science of the Total Environment*, *530-531,* 323-32. doi: 10.1016/j.scitotenv.2015.05.027

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 physiology does not indicate a terrestrial surficial source."[218]

- 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.[219]

- 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.[220] 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."[221]

- 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.[222] However, Siegel

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[218] Akob, D. M., Cozzarelli, I. M., Dunlap, D. S., Rowan, E. L., & Lorah, M. M. (2015). Organic and inorganic composition and microbiology of produced waters from Pennsylvania shale gas wells. *Applied Geochemistry,* in press, corrected proofs online April 20. doi: 10.1016/j.apgeochem.2015.04.011

[219] Lester, Y., Ferrer, I., Thurman, E. M., Sitterley, K. A., Korak, J. A., Aiken, G., & Linden, K. G. (2015). Characterization of hydraulic fracturing flowback water in Colorado: Implications for water treatment. *Science of the Total Environment, 512-513,* 637-644. doi: 10.1016/j.scitotenv.2015.01.043

[220] Heilweil, V. M., Grieve, P. L., Hynek, S. A., Brantley, S. L., Solomon, D. K., & Risser, D. W. (2015). Stream measurements locate thermogenic methane fluxes in groundwater discharge in an area of shale-gas development. *Environmental Science & Technology, 49,* 4057-4065. doi: 10.1021/es503882b

[221] U.S. Geological Survey. (2015, April 1). New stream monitoring method locates elevated groundwater methane in shale-gas development area. Retrieved from http://www.usgs.gov/newsroom/article.asp?ID=4176&from=rss&utm_source=dlvr.it&utm_medium=facebookhttp://www.readcube.com/articles/10.1002%2F2014WR016382?r3_referer=wol&tracking_action=preview_click&show_checkout=1&purchase_site_license=LICENSE_DENIED_NO_CUSTOMER#.VaPKNYsqdyA

[222] Siegel, D. I., Azzolina, N. A., Smith, B. J., Perry, A. E., & Bothun, R. L. (2015). Methane concentrations in water wells unrelated to proximity to existing oil and gas wells in northeastern Pennsylvania. *Environmental Science & Technology, 49,* 4106-12. doi: 10.1021/es505775c

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 a consultant in the energy sector.[223]

- 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.[224]

- 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.[225]

- 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

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[223] Siegel, D. I., Azzolina, N. A., Smith, B. J., Perry, A. E., & Bothun, R. L. (2015). Correction to Methane concentrations in water wells unrelated to proximity to existing oil and gas wells in northeastern Pennsylvania. *Environmental Science & Technology, 49,* 4106-12. doi: 10.1021/es505775c
[224] Alawattegama, S. K., Kondratyuk, T., Krynock, R., Bricker, M., Rutter, J. K., Bain, D. J., & Stolz, J. F. (2015). Well water contamination in a rural community in southwestern Pennsylvania near unconventional shale gas extraction. *Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances and Environmental Engineering, 50,* 516-528. doi: 10.1080/10934529.2015.992684
[225] Lampe, D. J., & Stolz, J. F. (2015). Current perspectives on unconventional shale gas extraction in the Appalachian Basin. *Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances and Environmental Engineering*, *50*(5), 434-446. doi: 10.1080/10934529.2015.992653

salts."[226]

- February 14, 2015 – A review by a *Dickinson Press* news reporter of disposal well files 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 well bore 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.[227]

- 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.[228]

- 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.[229] Dr. Imma Ferrer, lead author, explained in a *Science Daily* article about her research that "[b]efore we can

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[226] Bern, C. R., Clark, M. L., Schmidt, T. S., Nolloway, J. M., & McDougal, R. R. (2015). Soil disturbance as a driver of increased stream salinity in a semiarid watershed undergoing energy development. *Journal of Hydrology, 524,* 123-136. doi: doi.org/10.1016/j.jhydrol.2015.02.020

[227] Brown, A. (2015, February 14). Lacking integrity? State regulatory officials don't follow EPA guidance on saltwater disposal wells. *The Dickinson Press.* Retrieved from http://www.thedickinsonpress.com/energy/bakken/3679507-lacking-integrity-state-regulatory-officials-dont-follow-epa-guidance

[228] Cart. J. (2015, February 11). High levels of benzene found in fracking waste water. *Los Angeles Times.* Retrieved from http://www.latimes.com/local/california/la-me-fracking-20150211-story.html#page=1

[229] Ferrer, I. & Thurman, E.M. (2015), Chemical constituents and analytical approaches for hydraulic fracturing waters. *Trends in Environmental Analytical Chemistry*, *5,* 18-25, doi: 10.1016/j.teac.2015.01.003

assess the environmental impact of the fluid, we have to know what to look for."[230]

- 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.[231] 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."[232]

- January 21, 2015 – A team of researchers from the USGS and Virginia Tech University established that petroleum-based hydocarbons 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.[233] 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.[234]

- 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.[235] In an interview with the *Pittsburgh Post-Gazette*, lead author Avner Vengosh said that the findings raise new concerns about the environmental and health

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[230] Elsevier. (2015 April 8). Fracking fluids contain potentially harmful compounds if leaked into groundwater. *ScienceDaily*. Retrieved from http://www.sciencedaily.com/releases/2015/04/150408090323.htm?utm_source=feedburner&utm_medium=email&utm_campaign=Feed%3A+sciencedaily%2Fearth_climate%2Frecycling_and_waste+%28Recycling+and+Waste+News+--

[231] Bowen, Z. H., Oeisner, G. P., Cade, B., Gallegos, T. J., Farag, A. M., Mott, D. N., . . . Varela, B. A. (2015). 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,* 704-15. doi: 10.1002/2014WR016382

[232] Phillips, S. (2015, March 3). USGS: fracking water quality data "scarce." *StateImpact Pennsylvania.* Retrieved from https://stateimpact.npr.org/pennsylvania/2015/03/03/usgs-fracking-water-quality-data-scarce/

[233] U.S. Geological Survey (2015, January. 26). Natural breakdown of petroleum underground can lace arsenic into groundwater. Retrieved from http://www.usgs.gov/newsroom/article.asp?ID=4110&from=rss&utm_source=dlvr.it&utm_medium=facebook#.VavGXIsqdyA

[234] Cozzarelli, I. M. Schreiber, M. D., Erickson, M. L., & Ziegler, B. A. (2015). Arsenic cycling in hydrocarbon plumes: secondary effects of natural attenuation. *Groundwater*. doi: 10.1111/gwat.12316

[235] 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: 10.1021/es504654n

impacts of wastewater from drilling and fracking operations.[236]

- 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.[237] 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."[238]

- 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.[239]

- 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

[236] Hopey, D. (2015, January 15). Study: high levels of pollutants from drilling waste found in Pa. rivers. *Pittsburgh Post-Gazette*. Retrieved from 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

[237] Darrah, T. H., Vengosh, A., Jackson, R. B., Warner, N. R., & Poreda, R. J. (2014). Noble gases identify the mechanisms of fugitive gas contamination in drinking-water wells overlying the Marcellus and Barnett Shales. *Proceedings of the National Academy of Sciences, 111* (39), 14076-14081. doi: 10.1073/pnas.1322107111

[238] Jackson, R. (2014, December 1). Reopen Barnett Shale water probe. *The Texas Tribune.* Retrieved from http://tribtalk.org/2014/12/01/reopen-barnett-shale-water-probe/

[239] Kahrilas, G. A. Blotevogel, J., Stewart, P. S., & Borch, T. (2015). Biocides in hydraulic fracturing fluids: a critical review of their usage, mobility, degradation, and toxicity. *Environmental Science & Technology, 49*,16-32. doi: 10.1021/es503724k

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."[240]

- 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."[241]

- 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.[242]

- 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.[243]

- 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

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[240] Board, G. (2014, November 3). September drilling accident contaminated water in Doddridge County. *West Virginia Public Broadcasting*. Retrieved from http://wvpublic.org/post/dep-september-drilling-accident-contaminated-water-doddridge-county

[241] Schaeffer, E., & Bernhardt, C. (2014, October 22). Fracking's toxic loophole. The Environmental Integrity Project. Retrieved from http://environmentalintegrity.org/wp-content/uploads/FRACKINGS-TOXIC-LOOPHOLE.pdf

[242] Warner, N. R., Darrah, T. H., Jackson, R. B., Millot, R., Kloppmann, W., & Vengosh, A. (2014). New tracers identify hydraulic fracturing fluids and accidental releases from oil and gas operations. *Environ. Sci. Technol.*, *48*(21), 12552–12560. doi: 10.1021/es5032135

[243] Hopey, D. (2014, October 15). Waynesburg officials investigate dumping of fracking wastewater. *Pittsburgh Post-Gazette*. Retrieved from http://powersource.post-gazette.com/news/environment/2014/10/15/Waynesburg-investigates-dumping-of-fracking-wastewater/stories/201410150056

from a drilling site and fracking waste pit where multiple spills and leaks more than four years earlier had contaminated two springs.[244]

- 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 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."[245] 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.[246, 247]

- 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.[248]

- 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

[244] Hopey, D. (2014, October 6). Testimony: obsolete tests tainted shale analysis. *Pittsburgh Post-Gazette.* Retrieved from http://powersource.post-gazette.com/powersource/companies-powersource/2014/10/06/Testimony-Obsolete-tests-tainted-shale-analysis/stories/201410060075
[245] U.S. Government Accountability Office. (2014, September 23). Drinking water: characterization of injected fluids associated with oil and gas production. GAO-14-657R. Retrieved from http://www.gao.gov/products/GAO-14-857R.
[246] Sadasivam N. (2014, July 29). Report criticizes EPA oversight of injection wells, *ProPublica.* Retrieved from http://www.propublica.org/article/report-criticizes-epa-oversight-of-injection-wells
[247] U.S. Government Accountability Office. (June 27, 2014). EPA program to protect underground sources from injection of fluids associated with oil and gas production needs improvement. GAO-14-555. Retrieved from http://www.gao.gov/products/GAO-14-555
[248] Hopey, D. (2014, September 18). Range resources to pay $4.15M penalty. *Pittsburgh Post-Gazette*. Retrieved from http://www.post-gazette.com/local/2014/09/18/DEP-orders-Range-Resources-to-pay-4-million-fine/stories/201409180293

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.[249]

- September 9, 2014 – A research team from Stanford and Duke Universities discovered that fracking wastewater processed by sewage treatment plants contributes to the 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.[250]

- 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."[251, 252]

- 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

[249] Brittingham, M. C., Maloney, K. O., Farag, A. M., Harper, D. D., & Bowen, Z. H. (2014). Ecological risks of shale oil and gas development to wildlife, aquatic resources and their habitats. *Environmental Science & Technology*, *48*(19), 11034–11047. doi: dx.doi.org/10.1021/es5020482
[250] Parker, K. M., Zeng, T., Harkness, J., Vengosh, A., & Mitch, W. A. 2014. Enhanced formation of disinfection byproducts in shale gas wastewater-impacted drinking water supplies. *Environmental Science & Technology*, *48*(19), 11161–11169. doi: 10.1021/es5028184
[251] Pennsylvania Department of Environmental Protection. (2014 August 29). Water supply determination letters. Retrieved from http://files.dep.state.pa.us/OilGas/BOGM/BOGMPortalFiles/OilGasReports/Determination_Letters/Regional_Determination_Letters.pdf
[252] Legere, L. (2014, September 9). DEP releases updated details on water contamination near drilling sites: some 240 private supplies damaged by drilling in the past 7 years. *Pittsburgh Post-Gazette.* Retrieved from http://powersource.post-gazette.com/powersource/policy-powersource/2014/09/09/DEP-releases-details-on-water-contamination/stories/201409090010

with high diesel content for sale online, including over a dozen products sold by Halliburton and advertised as additives, friction reducers, emulsifiers, etc.[253]

- 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 fracking waste will magnify its toxic potency, as will reusing and recycling it.[254] The European Commission subsequently published a summary of these findings.[255]

- 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.[256, 257]

- 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.[258]

- 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

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[253] Greene, M. (2014, August 13). Fracking beyond the law: Despite industry denials, investigation reveals continued use of diesel in hydraulic fracturing. The Environmental Integrity Project. Retrieved from http://environmentalintegrity.org/wp-content/uploads/Fracking-Beyond-the-Law.pdf

[254] Maguire-Boyle, S. J., & Barron, A. R. (2014). Organic compounds in produced waters from shale gas wells. *Environ. Sci.: Processes Impacts, 16,* 2237-2248. doi: 10.1039/C4EM00376D

[255] European Commission. (2015, February 19). Chemical composition of fracking wastewater. *Science for Environment Policy, 404.* Retrieved from http://ec.europa.eu/environment/integration/research/newsalert/pdf/chemical_composition_of_fracking_wastewater_404na4_en.pdf

[256] Stringfellow, W. T., Domen, J. K., Carmarillo, M. K., Sandelin, W. L., Tinnacher, R., Jordan, P., . . . Birkholzer, J. (August 13, 2014). Characterizing compounds used in hydraulic fracturing: a necessary step for understanding environmental impacts. Presentation before the American Chemical Society conference, San Francisco. Abstract retrieved from http://abstracts.acs.org/chem/248nm/program/view.php?obj_id=262051&terms=

[257] Robinson, P. (2014, August 19). Fracking fluid survey shows missing information. *Scientific American.* Retrieved from http://www.scientificamerican.com/article/fracking-fluid-survey-shows-missing-information/

[258] Banerjee, N. (2014, August 12). Oil companies fracking into drinking water sources, new research finds. *Los Angeles Times.* Retrieved from http://www.latimes.com/nation/la-na-fracking-groundwater-pavillion-20140811-story.html#page=1

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.[259]

- 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 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.[260]

- 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."[261]

- 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.[262]

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[259] Hamill, S. D. (2014, August 3). Drillers did not report half of spills that led to fines. *Pittsburgh Post-Gazette*. Retrieved from http://www.post-gazette.com/news/state/2014/08/03/Drillers-did-not-report-half-of-spills-that-led-to-fines/stories/201408020142

[260] Arenschield, L. (2014, July 21). Halliburton delayed releasing details on fracking chemicals after Monroe County spill. *The Columbus Dispatch*. Retrieved from http://www.dispatch.com/content/stories/local/2014/07/21/details-on-chemicals-trickle-in-after-spill.html

[261] Burton Jr., G. A., Basu, N., Ellis, B. R., Kapo, K. E., Entrekin, S. & Nadelhoffer, K. (2014). Hydraulic "fracking": are surface water impacts an ecological concern? *Environmental Toxicology and Chemistry*, *33*(8), 1679-1689.

[262] Lustgarten, A. (2014, July 18). California halts injects of fracking waste, warning it may be contaminating aquifers. *ProPublica.* Retrieved from http://www.propublica.org/article/ca-halts-injection-fracking-waste-warning-may-be-contaminating-aquifers

- 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.[263]

- 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 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.[264]

- 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."[265]

- 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.[266]

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[263] Sang, W., Stoof, C., Zhang, W., Morales, V., Gao, B., Kay, R., . . . Steenhuis, T. (2014). Effect of hydrofracking fluid on colloid transport in the unsaturated zone. *Environmental Science & Technology*, *48*(14), 8266–8274. Retrieved from http://pubs.acs.org/doi/abs/10.1021/es501441e

[264] The Endocrine Society (2014, June 23). Hormone-disrupting activity of fracking chemicals worse than initially found. *Science Daily.* Retrieved from 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

[265] Yen, H. (2014, May 11). Fed govt failed to inspect higher risk oil wells. *Associated Press*. Retrieved from http://bigstory.ap.org/article/fed-govt-failed-inspect-higher-risk-oil-wells

[266] Davies, R. J., Almond, S., Ward, R. S., Jackson, R. B., Adams, C., Worrall, F., . . . Whitehead, M. A. (2014). Oil and gas wells and their integrity: Implications for shale and unconventional resource exploitation. *Marine and Petroleum Geology, 56*, 239-254. doi: 10.1016/j.marpetgeo.2014.03.001

- 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."[267]

- 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 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."[268]

- 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.[269]

- 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.[270] A letter sent to the EPA from more than 200 environmental organizations called on the agency to re-open its investigation.[271]

- 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

[267] Vengosh, A., Jackson, R. B., Warner, N., Darrah, T. H., & Kondash, A. (2014). A critical review of the risks to water resources from unconventional shale gas development and hydraulic fracturing in the United States [Abstract]. *Environmental Science & Technology*. doi: 10.1021/es405118y
[268] Gibbons, B. (2014, February 19). Woman wins case against Chesapeake Jaqueline Place of Terry Township to receive compensation for well contamination. *Thedailyreview.com*. Retrieved from http://thedailyreview.com/news/woman-wins-case-against-chesapeake-jaqueline-place-of-terry-township-to-receive-compensation-for-well-contamination-1.1636832
[269] Tomasic, J. (2014, January 16). Colorado drilling data: More than a spill a day. *The Colorado Independent*. Retrieved from http://www.coloradoindependent.com/145629/colorado-drilling-data-more-than-a-spill-a-day
[270] Drajem, M. (2014, January 9). Duke fracking tests reveal dangers driller's data missed. *Bloomberg*. Retrieved from http://www.bloomberg.com/news/2014-01-10/epa-s-reliance-on-driller-data-for-water-irks-homeowners.html
[271] Drajem, M. (2014, January 27). EPA needs fracking review: 'Gasland' maker, environmentalists. *Bloomberg*. Retrieved from http://go.bloomberg.com/political-capital/2014-01-27/epa-needs-fracking-review-gasland-producer-environmentalists-say/.

happens."[272]

- 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.[273] As reported by *Business Insider*, "The EPA Screwed Up When It Dropped This Fracking Investigation."[274]

- 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. [275, 276, 277]

- 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."[278]

- November 28, 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

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[272] Begos, K. (2014, January 05). 4 states confirm water pollution from drilling. *USA Today*. Retrieved from http://www.usatoday.com/story/money/business/2014/01/05/some-states-confirm-water-pollution-from-drilling/4328859/

[273] Banjeree, N. (2013, December 24). EPA report on fracking in Texas raises new concerns. *Los Angeles Times*. Retrieved from http://www.latimes.com/nation/la-na-epa-fracking-20131225,0,6042944.story#ixzz2oVB9FXVY

[274] Miedema, D. (2013, December 25). The EPA screwed up when it dropped this fracking investigation. *Business Insider*. Retrieved from http://www.businessinsider.com/epa-criticized-for-dropping-fracking-investigation-2013-12

[275] Kassotis, C. D., Tillitt, D. E., Davis, J. W., Hormann, A. M., & Nagel, S. C. (2013). Estrogen and androgen receptor activities of hydraulic fracturing chemicals and surface and ground water in a drilling-dense region. *Endocrinology*. doi: 10.1210/en.2013-1697

[276] 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

[277] Endocrine Society. (2013, December 16). Fracking chemicals disrupt hormone function. *ScienceDaily.* Retrieved from www.sciencedaily.com/releases/2013/12/131216140428.htm

[278] Hirst, C., & Fuquay, J. (2013, December 7). Second leak reported at east Fort Worth gas well site. *Star-Telegram*. Retrieved from http://www.star-telegram.com/2013/12/07/5399740/second-leak-reported-at-east-fort.html?rh=1

accidentally discovered by a wheat farmer. Even small spills can contaminate water sources permanently and take cropland out of production.[279]

- 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.[280, 281] 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.[282]

- 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 "leaving behind an imprint on the land as distinct as the ones left by the receding ice sheets of the ice age."[283]

- 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.[284]

- 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

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[279] MacPherson, J. (2013, October 28). Nearly 300 pipeline spills in North Dakota have gone unreported to the public since January 2012. *Huffington Post*. Retrieved from http://www.huffingtonpost.com/2013/10/28/pipeline-spills-north-dakota_n_4170133.html?ncid=edlinkusaolp00000003

[280] Kappel, W. M., Williams, J. H., & Szabo, Z. (2013). Water resources and shale gas/oil production in the Appalachian Basin - Critical issues and evolving developments. *U.S. Geological Survey*. Retrieved from http://pubs.usgs.gov/of/2013/1137/pdf/ofr2013-1137.pdf

[281] Mall, A. (2013, November 26). New USGS analysis: Threats to water, wildlife, and health from oil and gas development in the Appalachian basin [Web log post]. Retrieved from http://switchboard.nrdc.org/blogs/amall/new_usgs_analysis.html

[282] National Intelligence Council. (2012, February 2). *Global Water Security: Intelligence Community Assessment*, (ICA 2012-08). Retrieved from http://www.dni.gov/files/documents/Special%20Report_ICA%20Global%20Water%20Security.pdf

[283] Vaidyanathan, G. (2013, November 22). Bakken shale: As oil production sets in, pollution starts to migrate -- scientists. *E&E Publishing, LLC*. Retrieved from http://www.eenews.net/stories/1059990892

[284] Maykuth, A. (2013, September 13). Shale criminal charges stun drilling industry. *Philly.com*. Retrieved from http://articles.philly.com/2013-09-13/news/42012429_1_xto-energy-inc-criminal-charges-attorney-general

George Washington National Forest until the process can be proven safe.[285] 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.[286]

- September 3, 2013 – The North Dakota Department of Mineral Resources voiced concern about an increasing number of fracking well blowouts (23 incidents in the past year) that result in spills and public safety threats.[287]

- 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.[288]

- July 25, 2013 – A University of Texas at Arlington study of drinking water found elevated levels of arsenic and other heavy metals in some samples from private drinking water wells located within five kilometers of active natural gas wells in the Barnett Shale.[289]

- July 3, 2013 – *ProPublica* reported that the EPA was wrong to have halted its investigation of water contamination in Wyoming, Texas and Pennsylvania—where high levels of benzene, methane, arsenic, oil, methane, copper, vanadium, and other chemicals associated with fracking operations have been documented.[290] Although numerous organizations and health professionals around the country have since called on the agency to resume its investigation, no action has been taken.

- June 6, 2013 – Reviewing hundreds of regulatory and legal filings, *Bloomberg News* reported that drillers have offered out-of-court cash settlements and property buyouts to homeowners who claim that fracking ruined their water. These agreements typically come with gag orders and sealed records. This strategy, the investigation noted, allows the industry to continue claiming that no cases of water contamination due to fracking have ever been confirmed, impedes public health research, and shields data from

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285 Letter from George Hawkins, General Manager, DC Water, to U.S. Secretary of Agriculture, Thomas Vilsack, (Sept. 10, 2013), http://www.washingtoncitypaper.com/blogs/housingcomplex/2013/09/20/dc-water-chief-urges-agriculture-secretary-not-to-allow-fracking-near-d-c/

286 Wiener, A. (2013, September 20). DC Water Chief urges Agriculture Secretary not to allow fracking near D.C. *Washington City Paper*. Retrieved from http://www.washingtoncitypaper.com/blogs/housingcomplex/2013/09/20/dc-water-chief-urges-agriculture-secretary-not-to-allow-fracking-near-d-c/

287 Sun Staff. (2013, September 3). More blowouts a concern for N.D. *The Jamestown Sun*. Retrieved from http://www.jamestownsun.com/content/more-blowouts-concern-nd

288 Papoulias, D., & MacKenzie, T. (2013, August 28). Hydraulic fracturing fluids likely harmed threatened Kentucky fish species. *USGS Newsroom*. Retrieved from http://www.usgs.gov/newsroom/article.asp?ID=3677

289 Fontenot, B. E., Hunt, L. R., Hildenbrand, Z. L., Carlton Jr., D. D., Oka, H., Walton, J. L., . . . Schug, K. A. (2013). An evaluation of water quality in private drinking water wells near natural gas extraction sites in the Barnett Shale formation. *Environmental Science & Technology*, *47*(17), 10032-10040. doi: 10.1021/es4011724

290 Lustgarten, A. (2013, July 3). EPA's abandoned Wyoming fracking study one retreat of many. *ProPublica*. Retrieved from http://www.propublica.org/article/epas-abandoned-wyoming-fracking-study-one-retreat-of-many

regulators, policy makers, and the new media.[291] The EPA also long ago noted how non-disclosure agreements between oil and gas operators and landowners challenge scientific progress and keep examples of drilling harm secret from the public. In a 1987 report, the EPA wrote, "In some cases, even the records of well-publicized damage incidents are almost entirely unavailable for review. In addition to concealing the nature and size of any settlement entered into between the parties, impoundment curtails access to scientific and administrative documentation of the incident."[292]

- June 3, 2013 – A study by Duke University researchers linked fracking with elevated levels of methane, ethane, and propane in nearby groundwater.[293] Published in *Proceedings of the National Academy of Sciences*, the study included results from 141 northeastern Pennsylvania water wells. Methane levels were, on average, six times higher in drinking water wells closer to drilling sites when compared with those farther away, while ethane was 23 times higher.[294]

- May 19, 2013 – In Pennsylvania, the *Scranton Times-Tribune* released details of an investigation that revealed at least 161 cases of water contamination from fracking between 2008 and the fall of 2012, according to state Department of Environmental Protection records.[295]

- April 2013 – Researchers analyzing publicly available Colorado data found 77 surface spills impacting groundwater in Weld County alone. Samples of these spills often exceeded drinking water maximum contaminant levels (MCLs) for benzene, toluene, ethylbenzene and xylene; for benzene, a known carcinogen, 90 percent of the samples exceeded the legal limit.[296]

- March 4, 2013 – Researchers at the University of Pittsburgh Graduate School of Public Health analyzed samples of gas drilling wastewater discharged to surface water through

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[291] Efstathiou, J., Jr., & Drajem, M. (2013, June 5). Drillers silence fracking claims with sealed settlements. *Bloomberg*. Retrieved from http://www.bloomberg.com/news/2013-06-06/drillers-silence-fracking-claims-with-sealed-settlements.html
[292] Environmental Protection Agency. (1987). *Report to Congress: Management of wastes from the exploration, development, and production of crude oil, natural gas, and geothermal energy* (Rep.). 137-138. Washington, D.C.: U.S. Environmental Protection Agency.
[293] Jackson, R. B., Vengosh, A., Darrah, T. H., Warner, N. R., Down, A., Poreda, R. J., . . . Karr, J. D. (2013). Increased stray gas abundance in a subset of drinking water wells near Marcellus shale gas extraction. *Proceedings of the National Academy of Sciences*, 110(28), 11250-11255. doi: 10.1073/pnas.1221635110
[294] CBS/AP. (2013, June 25). Methane found in Pa. drinking water near fracked wells. *CBS News*. Retrieved from http://www.cbsnews.com/news/methane-found-in-pa-drinking-water-near-fracked-wells/
[295] Legere, L. (2013, May 19). Sunday Times review of DEP drilling records reveals water damage, murky testing methods. *The Times-Tribune*. Retrieved from http://thetimes-tribune.com/news/sunday-times-review-of-dep-drilling-records-reveals-water-damage-murky-testing-methods-1.1491547
[296] Gross, S. A., Avens, H. J., Banducci, A. M., Sahmel, J., Panko, J. M., & Tvermoes, B. E. (2013). Analysis of BTEX groundwater concentrations from surface spills associated with hydraulic fracturing operations. *Journal of the Air & Waste Management Association, 63*(4), 424-432. doi: 10.1080/10962247.2012.759166

wastewater treatment plants. Barium, strontium, bromides, chlorides, and benzene all exceeded levels known to cause human health impacts.[297]

- December 9, 2012 – State data in Colorado showed more than 350 instances of groundwater contamination resulting from more than 2,000 spills from oil and gas operations over the past five years. Further, as the *Denver Post* reported, "Contamination of groundwater—along with air emissions, truck traffic and changed landscapes—has spurred public concerns about drilling along Colorado's Front Range."[298]

- May 4, 2012 – A report for the Canadian Government, released under the Access to Information Act, reviewed the process, the regulatory framework globally, and the potential health hazards related to shale gas extraction. Additionally, the report evaluated mechanisms for potential impacts and summarized the data knowledge and data gaps. Regarding water contamination, the report determined, "Although quantitative data are lacking, the qualitative data available indicate that potential contamination of water related to the shale gas industry may present hazard to the public health, especially for local population." Regarding air contamination: "air emissions related to the shale gas industry present health hazards since the air pollutants originating from the vehicles and engines fuelled by diesel are toxic to the respiratory and cardiovascular systems and can cause premature mortality, volatile organic compounds have been associated to neurotoxicity and some of these compounds (e.g. benzene) as well as NORMs are known or possible human carcinogens." The report concluded, "Any step of shale gas exploration/exploitation may represent a potential source of drinking water and air contamination; Hydraulic fracturing and wastewater disposal were identified as the main potential sources of risk."[299]

- May 2012 – A report by researchers at Natural Resources Defense Council and Carnegie Mellon University found that the options available for dealing with fracking wastewater are inadequate to protect public health and the environment, resulting in increasing quantities of toxic wastewater as an ongoing problem without a good solution.[300]

- January 11, 2012 – The USGS reported that the Marcellus Shale is already highly fractured and that numerous fissures naturally occurring within the formation could

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[297] Ferrar, K. J., Michanowicz, D. R., Christen, C. L., Mulcahy, N., Malone, S. L., & Sharma, R. K. (2013). Assessment of effluent contaminants from three facilities discharging Marcellus shale wastewater to surface waters in Pennsylvania. *Environmental Science & Technology, 47*(7), 3472-3481. doi: 10.1021/es301411q

[298] Finley, B. (2012, December 9). Drilling spills reaching Colorado groundwater; state mulls test rules. *The Denver Post*. Retrieved from http://www.denverpost.com/environment/ci_22154751/drilling-spills-reaching-colorado-groundwater-state-mulls-test#ixzz2EihHU2fg

[299] Louis, S. (2012, May 4). Potential health hazards from shale gas exploration and exploitation–Drinking water and ambient air. Presented to Health Canada by SANEXEN Environmental Services; 0/Ref.: RA11-410. Document released under the (Canadian) Access to Information Act.

[300] Hammer, R., & VanBriesen, J. (2012, May). *In fracking's wake: New rules are needed to protect our health and environment from contaminated wastewater* (Rep.). Natural Resources Defense Council. Retrieved from http://www.nrdc.org/energy/files/fracking-wastewater-fullreport.pdf

potentially provide pathways for contaminants to migrate vertically into water supplies.[301]

- October 25, 2011 – After receiving new information from two companies, members of Congress updated their findings to show that "between 2005 and 2009, oil and gas service companies injected 32.7 million gallons of diesel fuel or hydraulic fracturing fluids containing diesel fuel in wells in 20 states."[302]

- October 17, 2011 – Thomas P. Jacobus, General Manager of the U.S. Army Corps of Engineers' Washington Aqueduct, called for a prohibition on horizontal hydraulic fracturing in the George Washington National Forest because of concern that fracking poses risks to drinking water. The Washington Aqueduct—which provides drinking water to Washington, DC, Arlington County, Virginia, and Falls Church, Virginia—is supplied by the Potomac River, which has its headwaters in the George Washington National Forest that sits atop the Marcellus Shale. Jacobus said, "Enough study on the technique [hydraulic fracturing] has been published to give us great cause for concern about the potential for degradation of the quality of our raw water supply…."[303]

- October 11, 2011 – Charles M. Murray, General Manager of Fairfax Water, called for a prohibition on horizontal hydraulic fracturing in the George Washington National Forest. "Natural gas development activities have the potential to impact the quantity and quality of Fairfax Water's source water," Murray wrote. "Downstream water users and consumers will bear the economic burden if drinking water sources are contaminated or the quality of our source water supply is degraded."[304] Fairfax Water provides drinking water for Fairfax County in Virginia.

- September 7, 2011 – In its draft Supplemental Generic Environmental Impact Statement (SGEIS), the New York State Department of Environmental Conservation (NYS DEC) acknowledged that "there is questionable available capacity"[305] for New York's public sewage treatment plants to accept drilling wastewater, yet the agency said that it would

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[301] U.S. Geological Survey, New York Water Science Center. (2012, January 11). *Comments on the revised draft supplemental generic environmental impact statement*. (Rep.). Retrieved from http://www.ewg.org/sites/default/files/report/ReviseddraftSGEIS_USGScomments_Version3_0.pdf

[302] Waxman, H. A., Markey, E. J., & DeGette, D. (2011, October 25). *Committee on Energy & Commerce* (U.S.A., Congress, Committee on Energy & Commerce). Retrieved from http://democrats.energycommerce.house.gov/index.php?q=news/reps-waxman-markey-and-degette-report-updated-hydraulic-fracturing-statistics-to-epa

[303] Jacobus, T. P. (2012, April 25). Draft environmental impact statement for the George Washington National Forest [Letter written October 17, 2011 to K. Landgraf]. Retrieved, from http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5366331.pdf

[304] Murray, C. M. (n.d.). Draft environmental impact statement for the George Washington National Forest [Letter written October 11, 2013 to K. Landgraf]. Retrieved from http://www.svnva.org/wp-content/uploads/fairfax-wash-aquaduct-gwnf-comments.pdf

[305] New York State Department of Environmental Conservation. (2011). *Supplemental generic environmental impact statement on the oil, gas and solution mining regulatory program, well permit issuance for horizontal drilling and high-volume hydraulic fracturing to develop the Marcellus shale and other low-permeability gas reservoirs* (6-62, Rep.).

allow those facilities to accept such waste if the plants meet permitting conditions.[306] The NYS DEC proposed underground injection as one alternative to sewage treatment procession of fracking waste. Although it is a common method of disposal for fracking wastewater,[307] the last significant government study of pollution risks from oil and gas wastewater injection wells occurred in 1989 and found multiple cases of costly groundwater contamination.[308] In subsequent years, studies have continued to link underground injection of drilling wastewater to pollution as well as earthquakes.[309]

- September 2011 – A team led by Theo Colburn of the Endocrine Disruptor Exchange found that 25 percent of chemicals known to be used in fracking fluids are implicated in cancer, 37 percent could disrupt the endocrine system, and 40-50 percent could cause nervous, immune and cardiovascular system problems. The research team also found that more than 75 percent could affect the skin, eyes, and respiratory system, resulting in various problems such as skin and eye irritation or flu-like symptoms.[310]

- August 4, 2011 – As reported by the *New York Times*, the EPA had alerted Congress in 1987 about a case of water contamination caused by fracking. Its report documented that a shale gas well hydraulically fractured at a depth of more than 4,200 feet contaminated a water supply only 400 feet from the surface.[311, 312, 313]

- May 17, 2011 – The state of Pennsylvania fined Chesapeake Energy Corporation $900,000 for an incident in which improper cementing and casing in one of the company's gas wells allowed methane to migrate underground and contaminate 16 private drinking water wells in Bradford County.[314]

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306 New York State Department of Environmental Conservation. (2011). *Supplemental generic environmental impact statement on the oil, gas and solution mining regulatory program, well permit issuance for horizontal drilling and high-volume hydraulic fracturing to develop the Marcellus shale and other low-permeability gas reservoirs* (6-57 through 6-63, Rep.).

307 New York State Department of Environmental Conservation. (2011). *Supplemental generic environmental impact statement on the oil, gas and solution mining regulatory program, well permit issuance for horizontal drilling and high-volume hydraulic fracturing to develop the Marcellus shale and other low-permeability gas reservoirs* (6-64, Rep.).

308 United States Government Accountability Office. (1989, July 5). Drinking water: Safeguards are not preventing contamination from injected oil and gas wastes. Retrieved from http://www.gao.gov/products/RCED-89-97

309 Fountain, H. (2012, January 1). Disposal halted at well after new quake in Ohio. *The New York Times*. Retrieved from http://www.nytimes.com/2012/01/02/science/earth/youngstown-injection-well-stays-shut-after-earthquake.html

310 Colborn, T., Kwiatkowski, C., Schultz, K., & Bachran, M. (2011). Natural gas operations from a public health perspective. *Human and Ecological Risk Assessment: An International Journal, 17*(5), 1039-1056. doi: 10.1080/10807039.2011.605662

311 Urbina, I. (2011, August 4). A tainted water well, and concern there may be more. Retrieved from http://www.nytimes.com/2011/08/04/us/04natgas.html

312 U.S. Environmental Protection Agency. (1987). *Report to Congress: Management of wastes from the exploration, development, and production of crude oil, natural gas, and geothermal energy* (Rep.). 4-22, 4-23. Retrieved from http://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=20012D4P.PDF

313 Horwitt, D. (2011, August 3). Cracks in the facade. *Environmental Working Group*. Retrieved from http://www.ewg.org/research/cracks-façade

314 Levy, M. (2011, May 18). DEP fines Chesapeake $1 million. *Pressconnects.com*. Retrieved from http://www.pressconnects.com/viewart/20110517/NEWS01/105170345/DEP-fines-Chesapeake-1-million

- May 17, 2011 – A Duke University study documented “systematic evidence for methane contamination of drinking water associated with shale gas extraction.”[315] The study showed that methane levels were 17 times higher in water wells near drilling sites than in water wells in areas without active drilling.[316]

- April 22, 2011 – Describing one of many blowouts, the Associated Press reported on a shale gas well in Canton, Pennsylvania that spewed thousands of gallons of chemical-laced water on farmland and into a stream for two consecutive days before being brought under control.[317]

- April 18, 2011 – As part of a year-long investigation into hydraulic fracturing and its potential impact on water quality, U.S. Representatives Henry Waxman (D-Calif.), Edward Markey (D-Mass.) and Diana DeGette (D-Colo.) released the second of two reports issued in 2011. Their analysis of hydraulic fracturing fluids used by the 14 leading oil and natural gas service companies between 2005 and 2009 found, among other things, that the companies used more than 650 different products that contained chemicals that are known or possible human carcinogens, regulated under the Safe Drinking Water Act, or listed as hazardous air pollutants under the Clean Air Act. The report also showed that “between 2005 and 2009, the companies used 94 million gallons of 279 products that contained at least one chemical or component that the manufacturers deemed proprietary or a trade secret … in most cases the companies stated that they did not have access to proprietary information about products they purchased ‘off the shelf’ from chemical suppliers. In these cases, the companies are injecting fluids containing chemicals that they themselves cannot identify.”[318] These findings were reported in the *New York Times*.[319]

- January 2011 – A team of scientists led by a University of Central Arkansas researcher called attention to the threat posed to surface waters by rapidly expanding shale gas development, noting a lack of data collection accompanying the rush to drill. “Gas wells are often close to surface waters that could be impacted by elevated sediment runoff from

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[315] Osborn, S. G., Vengosh, A., Warner, N. R., & Jackson, R. B. (2011). Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing. *Proceedings of the National Academy of Sciences*, *108,* 8172-8176. doi: 10.1073/pnas.1100682108

[316] Duke University. (2011). Methane levels 17 times higher in water wells near hydrofracking sites, study finds. *ScienceDaily*. Retrieved from http://www.sciencedaily.com/releases/2011/05/110509151234.htm

[317] The Associated Press. (2011, April 22). Crews stop flow of drilling fluid from Pennsylvania well. *Syracuse.com*. Retrieved from http://www.syracuse.com/news/index.ssf/2011/04/crews_stop_flow_of_drilling_fl.html

[318] Waxman, H. A., Markey, E. J., & DeGette, D. (2011, April 18). Committee on Energy & Commerce (U.S.A., Congress, Committee on Energy & Commerce). Retrieved from http://democrats.energycommerce.house.gov/sites/default/files/documents/Hydraulic-Fracturing-Chemicals-2011-4-18.pdf

[319] Urbina, I. (2011, April 17). Chemicals were injected into wells, report says. *The New York Times*. Retrieved from http://www.nytimes.com/2011/04/17/science/earth/17gas.html

pipelines and roads, alteration of stream flow as a result of water extraction, and contamination from introduced chemicals or the resulting wastewater."[320]

- January 31, 2011 – As part of a year-long investigation into hydraulic fracturing and its potential impact on water quality, U.S. Representatives Henry Waxman (D-Calif.), Edward Markey (D-Mass.) and Diana DeGette (D-Colo.) reported that "between 2005 and 2009, oil and gas service companies injected 32.2 million gallons of diesel fuel or hydraulic fracturing fluids containing diesel fuel in wells in 19 states." Furthermore, revealing apparent widespread violation of the Safe Drinking Water Act, the investigation found that no oil and gas service companies had sought—and no state or federal regulators had issued—permits for the use of diesel fuel in hydraulic fracturing.[321]

- April 29, 2010 – In 2010, the Colorado Oil and Gas Conservation Commission fined Occidental Petroleum Corporation (OXY) USA a record $390,000 for an incident of pollution, discovered in 2008, when its drilling wastes leaked through an unlined pit, contaminated two springs with benzene, and polluted other nearby water sources. In addition, the regulators separately fined OXY USA $257,400 for a nearby case of pollution, also discovered in 2008, in which a torn liner in a pit caused drilling waste fluids to leak out and contaminate two springs with benzene.[322]

- June 5, 2009 – A leaking pipe carrying fracking waste in Washington County, Pennsylvania, polluted a tributary of Cross Creek Lake, killing fish, salamanders, crayfish, and aquatic insect life in approximately three-quarters of a mile of the stream.[323]

- April 26, 2009 – Officials in three states linked water contamination and methane leaks to gas drilling. Incidents included a case in Ohio where a house exploded after gas seeped into its water well and multiple cases of exploding drinking water wells in Dimock, Pennsylvania.[324]

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[320] Entrekin, S., Evans-White, M., Johnson, B., & Hagenbuch, E. (2011). Rapid expansion of natural gas development poses a threat to surface waters. *Frontiers in Ecology and the Environment, 9*(9), 503-511. doi: 10.1890/110053

[321] Waxman, H. A., Markey, E. J., & DeGette, D. (2011, January 31). *Committee on Energy & Commerce* (U.S.A., Congress, Committee on Energy & Commerce). Retrieved from http://democrats.energycommerce.house.gov/index.php?q=news/waxman-markey-and-degette-investigation-finds-continued-use-of-diesel-in-hydraulic-fracturing-f

[322] Webb, D. (2010, April 29). Record fine, second one against Oxy approved. *Grand Junction Sentinel*. Retrieved from http://www.gjsentinel.com/news/articles/record-fine-second-one-against-oxy-approved

[323] Pittsburgh Post-Gazette. (2009, June 5). Waste from Marcellus shale drilling in Cross Creek Park kills fish. *Pittsburgh Post-Gazette*. Retrieved, from http://www.post-gazette.com/washington/2009/06/05/Waste-from-Marcellus-shale-drilling-in-Cross-Creek-Park-kills-fish/stories/200906050136

[324] Lustgarten, A. (2009, April 26). Officials in three states pin water woes on gas drilling. *ProPublica*. Retrieved from http://www.propublica.org/article/officials-in-three-states-pin-water-woes-on-gas-drilling-426

- November 13, 2008 – *ProPublica* reported more than 1,000 cases of drilling-related contamination documented by courts and state and local governments in Colorado, New Mexico, Alabama, Ohio, and Pennsylvania.[325]

- December 15, 2007 – In Bainbridge, Ohio, a gas well that was improperly cemented and subsequently fractured by Ohio Valley Energy Systems Corporation allowed natural gas to migrate outside of the well, causing a home to explode. In addition, 23 nearby water wells were contaminated, two of which were located more than 2,300 feet from the drilling site.[326, 327, 328]

Inherent engineering problems that worsen with time

Studies show that many oil and gas wells leak, allowing for the migration of natural gas and potentially other substances into groundwater and/or the atmosphere. According to Schlumberger, one of the world's largest companies specializing in fracking, about five percent of wells leak immediately, 50 percent leak after 15 years, and 60 percent leak after 30 years. Recent research suggests that the act of fracking itself creates pathways for leaks. The problem of leaking wells, identified by industry, has no known solution. Data from Pennsylvania's Department of Environmental Protection (DEP) agree, showing over nine percent of shale gas wells drilled in the state's northeastern counties leaking within the first five years. Leaks pose serious risks, including potential loss of life or property from explosions and migration of gas and other harmful chemicals into drinking water supplies. Methane leaking into aquifers, can under some conditions, be transformed by bacteria into hydrogen sulfide and other poisonous byproducts. Microbes from deep shale formations can likewise generate sulfides contributing, over time, to corrosion of pipes and casings.

Leaks also allow methane to escape into the atmosphere, where it acts as a more powerful greenhouse gas than carbon dioxide. There is no evidence to suggest that the problem of cement and well casing impairment is abating. Indeed, analysis of more than 75,000 compliance reports for more than 41,000 wells in Pennsylvania found that newer wells have higher leakage rates than older ones and that unconventional shale gas wells leak more than conventional wells drilled within the same time period. Industry has no solution for rectifying the chronic problem of well casing/cement failures and resulting leakage.

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[325] Lustgarten, A. (2008, November 13). Buried secrets: Is natural gas drilling endangering U.S. water supplies? *ProPublica*. Retrieved from http://www.propublica.org/article/buried-secrets-is-natural-gas-drilling-endangering-us-water-supplies-1113

[326] Ohio Department of Natural Resources Division of Mineral Resources Management. (2008, September 1). *Report on the investigation of the natural gas invasion of aquifers in Bainbridge Township of Geauga County, Ohio*. (Rep.). Retrieved from http://www.ohiodnr.com/mineral/bainbridge/tabid/20484/default.aspx

[327] Bair, E. S., Freeman, D. C., & Senko, J. M. (2010, June). *Expert panel technical report, subsurface gas invasion Bainbridge Township, Geauga County, Ohio* (Rep.). Retrieved from http://oilandgas.ohiodnr.gov/portals/oilgas/pdf/bainbridge/DMRM%200%20Title%20Page,%20Preface,%20Acknowledgements.pdf

[328] Ohio Department of Natural Resources, Order Number 2009-17 (Apr. 14, 2009) (see attachments A, B).

- November 23, 2017 – An investigative journalist from *The Tyee* in Vancouver obtained a copy of a 2013 report from British Columbia's Oil and Gas Commission warning about hundreds of uncontrolled methane leaks from shale gas wells located in the northern Rocky Mountain range near Fort Nelson. The commission's report, never shared with the public or with elected officials, remained an internal document until it was uncovered by the newspaper. Cornell University engineer Anthony Ingraffea, quoted in the story, said the report's findings served as another confirmation that wells leak badly and inevitably over time. "What do they expect from underground operations such as these, total obedience to design intent? Why are operators and regulators around the world seemingly surprised when things go wrong underground, and in so many ways, and so often?" Ingraffea said.[329, 330]

- July 5, 2017 – A team of researchers led by microbiologists from Ohio State University investigated bacteria from hydraulically fractured shale by sampling fracking wastewater from a well drilled in the Utica shale. The dominant microrganism was a bacterium that generates sulfides, which can contribute to corrosion of well casings. "The impact of microbial metabolism within these environments is poorly understood. . . . These findings emphasize the potential detrimental effects that could arise from thiosulfate-reducing microorganisms in hydraulically fractured shales, which are undetected by current industry-wide corrosion diagnostics."[331]

- July 9, 2015 – As part of a larger examination of the potential health and environmental impacts of fracking in California, the California Council on Science and Technology (CCST) documented cases of well failures triggered by underground movements that caused well casings to shear. Sheared well casings can allow gas and fluids from the fracking zone to migrate to overlying aquifers. The CCST team identified several mechanisms by which casing shears can occur in California as oil wells age: surface subsidence, heaving, reservoir compaction, and earthquakes. Prolonged drought can also damage the integrity of well casings: as groundwater levels fall, landforms can sink and contribute to casing shear.[332]

- June 30, 2015 – According to the New York State Department of Environmental Conservation (NYS DEC) Findings Statement, "there is a risk that well integrity can fail, especially over time, and questions have arisen about whether high-volume hydraulic fracturing can cause seismic changes which could potentially result in fracturing fluid migration through abandoned wells or existing fissures and faults. Thus, high-volume

[329] Nikiforuk, A. (2017, November 23). Despite what politicians say, hundreds of BC gas wells leak methane. *The Tyee.* Retrieved from https://thetyee.ca/News/2017/11/23/Hundreds-of-BC-Gas-Wells-Leak-Meth/
[330] BC Oil and Gas Commission. (2013, December). *Gas migration preliminary investigation report.* Retrieved from https://www.bcogc.ca/node/14620/download
[331] Booker, A. E., Borton, M. A., Daly, R. A., Welch, S. A., Nicora C. D., Hoyt, D. W., … Wilkins, M. J. (2017). Sulfide generation by dominant Halanaerobium microorganisms in hydraulically fractured shales. *mSphere, 2*(4), e00257-17. doi: 10.1128/mSphereDirect.00257-17
[332] Stringfellow, W. T., Cooley H., Varadharajan, C., Heberger, M., Reagan, M. T., Domen, J.K., Sandelin, W. … Houseworth, J. E. (2015, July 9). Volume II, Chapter 2: Impacts of well stimulation on water resources. In: *An Independent Scientific Assessment of Well Stimulation in California.* California Council on Science and Technology, Sacramento, CA. Retrieved from http://ccst.us/publications/2015/vol-II-chapter-2.pdf

hydraulic fracturing could result in significant adverse impacts to water resources from well construction and fracturing fluid migration."[333]

- June 4, 2015 – As part of a draft assessment of fracking's impact on drinking water, the U.S. EPA examined cases of water contamination across the United States and concluded that "construction issues, sustained casing pressure, and the presence of natural faults and fractures can work together to create pathways for fluids to migrate toward drinking water resources." Fracking older wells poses additional risks, the draft study notes, because aging itself "can contribute to casing degradation, which can be accelerated by exposure to corrosive chemicals, such as hydrogen sulfide, carbonic acid, and brines" and because many older wells were never designed to withstand the high pressures and stress of fracking operations. The EPA estimates that 6 percent of the 23,000 U.S. oil and gas wells (= 1,380 wells) first fracked in 2009 or 2010 were drilled more than ten years earlier.[334]

- December 2, 2014 – Problems with structural integrity have been documented in a well at the only hydraulically fractured site in the United Kingdom. Email messages obtained under freedom of information laws reveal that problems with wellbore integrity emerged in April of 2014 and attempts were made to remediate the problem, although nothing was reported at that time to regulators. The drilling company, Cuadrilla Resources, continues to deny that any problems exist with the well, emphasizing that "no leak of fluids" occurred and that "the issue" was resolved during the abandonment process. Cuadrilla had previously been reprimanded for failing to disclose a more minor deformation in the well casing. The well was abandoned at the end of last year, following two earthquakes in 2011, which scientists determined to have been caused by fracking at the site.[335]

- August 11, 2014 – Researchers affiliated with multiple universities and with the Los Alamos National Laboratory summarized recent field observations of wellbore-integrity failure, concluding that, because at least some well failures are not identified, reported barrier failure rates of 1-10 percent of wells and reported rates of groundwater contamination of 0.01-0.1 percent of wells constitute a "lower bound" for possible environmental problems. Citing hydraulic fracturing, as well as temperature and pressure changes, as operations that can induce pathways for leaks, the authors point out that few studies have considered the very-long-term fate (">50 years") of wellbore systems. They

[333] New York State Department of Environmental Conservation. (2015, June 30). *Final supplemental generic environmental impact statement on the oil, gas and solution mining regulatory program: Regulatory program for horizontal drilling and high-volume hydraulic fracturing to develop the Marcellus Shale and other low-permeability gas reservoirs, findings statement.* Retrieved from http://www.dec.ny.gov/docs/materials_minerals_pdf/findingstatehvhf62015.pdf

[334] U.S. Environmental Protection Agency (2015, June 30). *Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources*, executive summary (draft). Retrieved from http://www2.epa.gov/sites/production/files/2015-06/documents/hf_es_erd_jun2015.pdf

[335] Bryant, B. (2014, December 2). The only fracked site in the United Kingdom suffered structural failure. *Vice News*. Retrieved from https://news.vice.com/article/the-only-fracking-site-in-the-united-kingdom-suffered-structural-failure

include "whether unconventional resource development alters the frequency of well integrity failures" as a critical topic for future research.[336]

- July 30, 2014 – Based on records obtained from Pennsylvania's Department of Environmental Protection (PA-DEP), Scranton's *Times-Tribune* reported that five natural gas wells in Bradford County have leaked methane for years because of persistent casing and cement problems. In the most recent violation, a PA-DEP inspector found combustible gas flowing through vents connected to the cement between layers of pipe. The agency issued a notice of violation for each well, saying combustible gas outside the well's surface casing violates state regulations. Each of the wells has four layers of steel casing, but nothing prevents leaking (stray) methane from flowing into the atmosphere. No evidence of water contamination has yet been seen. None of the wells have produced any gas for sale.[337]

- June 30, 2014 – A study published in *Proceedings of the National Academy of Sciences* by a Cornell University research team projected that over 40 percent of shale gas wells in Northeastern Pennsylvania will leak methane into groundwater or the atmosphere over time. Analyzing more than 75,000 state inspections of more than 41,000 oil and gas wells in Pennsylvania since 2000, the researchers identified high occurrences of casing and cement impairments inside and outside the wells. A comparative analysis showed that newer, unconventional (horizontally fracked) shale gas wells were leaking at six times the rate of conventional (vertical) wells drilled over the same time period. The leak rate for unconventional wells drilled after 2009 was at least six percent, and rising with time. In the state's northeastern counties between 2000 and 2012, over nine percent of shale gas wells drilled leaked within the first five years.[338] The study also discovered that over 8,000 oil and gas wells drilled since 2000 had not received a facility-level inspection. This study helps explain the results of earlier studies that documented elevated levels of methane in drinking water aquifers located near drilling and fracking operations in Pennsylvania and points to compromised structural integrity of well casings and cement as a possible mechanism.

- May 22, 2014 – In a 69-page report, University of Waterloo researchers warned that natural gas seeping from 500,000 wellbores in Canada represents "a threat to environment and public safety" due to groundwater contamination, greenhouse gas emissions, and explosion risks wherever methane collects in unvented buildings and spaces. The report found that 10 percent of all active and suspended gas wells in British Columbia now leak methane. Additionally, the report found that some hydraulically fractured shale gas wells in that province have become "super methane emitters" that

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[336] Jackson R. B., Vengosh, A., Carey, J. W., Davies, R. J., Darrah, T. H., O'Sullivan, F., & Pétron, G. (2014). The environmental costs and benefits of fracking. *Annual Review of Environment and Resources, 39,* 327–62. doi: 10.1146/annurev-environ-031113-144051
[337] Gibbons, B. (2014, July 30). Five gas wells leaked methane for years. *Times-Tribune*. Retrieved from http://thetimes-tribune.com/news/five-gas-wells-leaked-methane-for-years-1.1727537
[338] Ingraffea, A., Wells, M., Santoro, R., & Shonkoff, S. (2014). Assessment and risk analysis of casing and cement impairment in oil and gas wells in Pennsylvania, 2000–2012. *Proceedings of the National Academy of Sciences*. Retrieved from http://www.pnas.org/content/early/2014/06/25/1323422111.abstract

spew as much as 2,000 kilograms of methane a year.[339, 340]

- May 1, 2014 – Following a comprehensive review of evidence, the Council of Canadian Academies identified inherent problems with well integrity as one of its top concerns about unconventional drilling and fracking. According to one expert panel, "the greatest threat to groundwater is gas leakage from wells from which even existing best practices cannot assure long-term prevention."[341] Regarding their concerns related to well integrity and cement issues, the panel wrote:

  > Two issues of particular concern to panel members are water resources, especially groundwater, and GHG emissions. Both related to well integrity…. Natural gas leakage from improperly formed, damaged, or deteriorated cement seals is a long-recognized yet unresolved problem …. Leaky wells due to improperly placed cement seals, damage from repeated fracturing treatments, or cement deterioration over time, have the potential to create pathways for contamination of groundwater resources and to increase GHG emissions.

  They further explain:

  > Cement may crack, shrink, or become deformed over time, thereby reducing the tightness of the seal around the well and allowing the fluids and gases … to escape into the annulus between casing and rock and thus to the surface…. The challenge of ensuring a tight cement seal [will] be greater for shale gas wells that are subjected to repeated pulses of high pressure during the hydraulic fracturing process than for conventional gas wells. This pressure stresses the casing and therefore the cement that isolates the well from surrounding formations repeatedly.

- January 8, 2013 – According to state inspections of all 6,000 wells drilled in Pennsylvania's Marcellus Shale before 2013, six to ten percent of them leaked natural gas, with the rate of leakage increasing over time. The rate was six percent in 2010 (97 well failures out of 1,609 wells drilled); 7.1 percent in 2011 (140 well failures out of 1,972 wells drilled); and 8.9 percent in 2012 (120 well failures out of 1,346 wells drilled).[342] These data include wells that were cited for leakage violations, and wells that were noted to be leaking by inspectors but which had not been given violations. The NYS DEC forecasts that 50,000 wells could be drilled over the life of the Marcellus Shale

[339] Dusseault, M. B., Jackson, R. E., & MacDonal, D. (2014, May 22). *Towards a road map for mitigating the rates and occurrences of long-term wellbore leakage*. Geofirma. Retrieved from http://geofirma.com/wp-content/uploads/2015/05/lwp-final-report_compressed.pdf

[340] Nikiforuk, A. (2014, June 5). Canada's 500,000 leaky energy wells: 'Threat to public' *The Tyee*. Retrieved from http://www.thetyee.ca/News/2014/06/05/Canada-Leaky-Energy-Wells/

[341] Council of Canadian Academies. (2014, May 1). *Environmental Impacts of Shale Gas Extraction in Canada: the Expert Panel on Harnessing Science and Technology to Understand the Environmental Impacts of Shale Gas Extraction.* Retrieved from http://bit.ly/1nNicuf

[342] Ingraffea, A. R. (2013). Some scientific failings within high volume hydraulic fracturing proposed regulations. Retrieved from http://www.psehealthyenergy.org/data/NYS_DEC_Proposed_REGS_comments_Ingraffea_Jan_2013.pdf

play. If they fail at the same rate as wells in Pennsylvania, 4,000 wells would fail and leak in New York almost immediately.[343]

- March 2009 – A study published by the Society of Petroleum Engineers of more than 315,000 oil, gas, and injection wells in Alberta, Canada, found that 4.5 percent of the wells had unintended gas flow to the surface. In one designated area, officials required testing for gas migration outside the well casings in addition to routine testing for gas leaks within the rings of steel casings (annuli). Within this special testing zone, 15.5 percent of wells (3,205 of 20,725) leaked gas, and the incidence of gas leaks was four times percent higher in horizontal or deviated wells than in vertical wells.[344]

- Autumn 2003 – Schlumberger, one of the world's largest companies specializing in hydraulic fracturing and other oilfield services, reported in its in-house publication, *Oilfield Review*, that more than 40 percent of approximately 15,500 wells in the outer continental shelf area in the Gulf of Mexico were leaking gas. These included actively producing wells, in addition to shut-in and temporarily abandoned wells. In many cases, the gas leaked through the spaces (annuli) between layers of steel casing that drilling companies had injected with cement precisely to prevent such gas leaks. Leakage rates increased dramatically with age: about five percent of the wells leaked immediately; 50 percent were leaking after 15 years; and 60 percent were leaking after about 30 years.[345] Gas leaks pose serious risks including loss of life from explosions and migration of gas and associated contaminants into drinking water supplies. Leaks also allow the venting of raw methane into the atmosphere where it acts as a powerful greenhouse gas.

- November 2000 – Maurice Dusseault, a specialist in rock mechanics at the University of Waterloo in Ontario, and two co-authors presented a paper published by the Society of Petroleum Engineers, in which they reported that oil and natural gas wells routinely leak gas through cracks in their cement casings, likely caused by cement shrinkage over time and exacerbated by upward pressure from natural gas. According to their paper, in Alberta, it is common for wells to leak natural gas into aquifers. "Because of the nature of the mechanism, the problem is unlikely to attenuate," they wrote, "and the concentration of the gases in the shallow aquifers will increase with time."[346]

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343 New York State Department of Environmental Conservation. (2011). *Supplemental generic environmental impact statement on the oil, gas and solution mining regulatory program, well permit issuance for horizontal drilling and high-volume hydraulic fracturing to develop the Marcellus shale and other low-permeability gas reservoirs* (2-1, Rep.).

344 Watson, T. L., & Bachu, S. (2009). Evaluation of the potential for gas and CO2 leakage along wellbores, Society of Petroleum Engineers. *SPE Drilling & Completion*, *24*, 115-126. doi: 10.21.18/106817-PA

345 Brufatto, C. (2003). From mud to cement - Building gas wells. *Oilfield Review*, *15*(3). Retrieved from http://www.slb.com/resources/publications/industry_articles/oilfield_review/2003/or2003aut06_building_gas_wells.aspx

346 Dusseault, M. B., Gray, M. N., & Nawrocki, P. A. (2000). Why oil wells leak: Cement behavior and long-term consequences. *Society of Petroleum Engineers*. Retrieved from http://www.hydrorelief.org/frackdata/references/65704543-Casing-Leaks.pdf

Radioactive releases

High levels of radiation documented in fracking wastewater from many shale formations raise special concerns in terms of impacts to groundwater and surface water. Measurements of radium in fracking wastewater in New York and Pennsylvania, from the particularly radioactive Marcellus Shale, have been as high as 3,600 times the regulatory limit for drinking water, as established by the U.S. Environmental Protection Agency (EPA). One study found toxic levels of radiation in a Pennsylvania waterway even after fracking wastewater was disposed of through an industrial wastewater treatment plant. The disposal of radioactive drill cuttings is an additional concern. A recent study found high levels of radon in buildings located in heavily drilled areas of Pennsylvania, with levels of radon rising since the start of the fracking boom. Unsafe levels of radon and its decay products in natural gas produced from the Marcellus Shale may also contaminate pipelines and compressor stations, as well as pose risks to end-users when allowed to travel into homes. There is no federal oversight and, in some cases, a total lack of state regulations for handling radioactive oil and gas waste. Increasing evidence documents illegal, haphazard dumping of radioactive fracking waste, along with its disposal in municipal landfills not engineered to contain radioactivity. North Dakota alone generates 70 tons per day of radioactive drilling and fracking waste.

- September 22, 2017 – State health regulators confirmed that unknown quantities of radioactive waste from drilling and fracking operations have been illegally buried in Colorado landfills not permitted to accept it.[347]

- November 23, 2016 – University of Iowa researchers evaluated radioactive materials—uranium, thorium, radium, lead, and polonium isotopes—from drill cutting samples extracted from a single well drilled in northern Pennsylvania. They found complex patterns of vertical stratification. For example, the deep drill cuttings had significantly more uranium (U) than the cuttings removed from shallow portions of the well. Noting that virtually all drill cutting waste from the Marcellus Shale is deposited in landfills, the authors examined the stability of the various radioactive materials by simulating different conditions of landfill leaching. The results suggested some environmental mobility of radionuclides in drill cuttings. In particular, as acidity increased, radionuclide leaching increased, with ^{238}U and ^{234}U being the most leachable radionuclides. The authors concluded, "Although previous studies have suggested that [radioactive materials] in drill cuttings pose a minimal health risk to the general public when deposited in landfills, our results indicate that Marcellus Shale drill cuttings warrant further radiochemical investigation."[348]

- April 27, 2016 – Duke University researchers who studied oil and gas wastewater

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[347] Finley, B. (2017, September 22). Colorado landfills are illegally burying low-level radioactive waste from oil and gas industry, Denver Post learns. *Denver Post.* Retrieved from https://www.denverpost.com/2017/09/22/colorado-landfills-illegally-burying-radioactive-waste-oil-gas/

[348] Eitrheim, E. S., May, D., Forbes, T. Z., & Nelson, A. W. (2016). Disequilibrium of naturally occurring radioactive materials (NORM) in drill cuttings from a horizontal drilling operation. *Environmental Science & Technology Letters 3*, 425-29. doi: 10.1021/acs.estlett.6b00439

(“brine”) spills reported that “the water contamination from brine spills is remarkably persistent in the environment, resulting in elevated levels of salts and trace elements that can be preserved in spill sites for at least months to years .…” In addition, radioactivity was elevated in soil and sediment sampled at spill sites, indicating that radium had accumulated in the soils of spill-affected areas.[349] The bigger the spill, the higher the soil radioactivity level. Study author Avner Vengosh told *InsideClimate News*, “We found even if you take away the spill water… you still left behind the legacy of radioactivity in the soils,” where it can linger for thousands of years.[350]

- March 10, 2016 – Louisville’s *Courier-Journal* reported on illegal dumping of radioactive oil and gas drilling wastes in two Kentucky landfills. Landfill operators in Greenup and Estill counties were issued violation notices for failing to “accurately characterize the waste for what it was, allowing what’s considered an illegal release of a hazardous material into the environment.” The illegal dumping at the Greenup County landfill alone consisted of 369 tons of radioactive drilling waste.[351]

- February 26, 2016 – Radioactive oil and gas waste from fracking operations in Ohio, Pennsylvania, and West Virginia was illegally sent to Estill County, Kentucky’s Blue Ridge Landfill. The radioactive level of the material that was buried “was at least 340 times more than the amount that is allowed to be buried at a solid waste landfill,” according to WKYT in Lexington. WKYT reported that Estill County leaders would “fight ‘tooth and toenail’ to get the bottom of how low-level radioactive waste ended up in a county landfill,” and do its own testing at the landfill and nearby schools.[352]

- November 23, 2015 – Absence of federal oversight and, in some cases, a total lack of state regulations for handling radioactive oil and gas waste was the topic of a report in *High Country News*, which detailed the regulatory situation in six Western states: Colorado, Idaho, Montana, North Dakota, South Dakota, and Wyoming. North Dakota alone generates an estimated 70 tons a day of radioactive oil and gas waste. “Because the waste is often too radioactive to be disposed of in landfills, it sometimes gets dumped illegally.” Proposed new rules in North Dakota would raise the radioactivity limit for the waste.[353]

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[349] Lauer, N. E., Harkness, J. S., & Vengosh, A. (2016). Brine spills associated with unconventional oil development in North Dakota. *Environmental Science & Technology, 50*(10), 5389–5397. doi: 10.1021/acs.est.5b06349
[350] Hirji, Z. (2016, April 29). Persistent water and soil contamination found at N.D. wastewater spills. *InsideClimate News*. Retrieved from http://insideclimatenews.org/news/29042016/north-dakota-wastewater-spill-water-soil-contaminiation-radium-selenium-bakken-oil
[351] Bruggers, J. (2016, March 10). State begins crackdown on radioactive waste. *Courier-Journal.* Retrieved from http://www.courier-journal.com/story/tech/science/environment/2016/03/08/state-orders-end-hauling-radioactive-waste/81496490/
[352] *WKYT*. (2016, February, 26). Estill County leaders to fight 'tooth and toenail' over radioactive waste in landfill. WKYT. Retrieved from http://www.wkyt.com/content/news/Estill-Co-leaders-to-fight-tooth-and-toenail-over-radioactive-waste-in-landfill-370308981.html
[353] Peterson, J. (2015, November 23). States lack rules for radioactive drilling waste disposal. *High Country News*. Retrieved from http://www.hcn.org/articles/states-lack-rules-for-handling-radioactive-drilling-waste

- July 8, 2015 – Radium-226 is the dominant radioactive material in flowback water from hydraulically fractured wells in the Marcellus Shale. A Pittsburgh team of researchers studied its fate in three wastewater storage pits in southwestern Pennsylvania over a 2.5-year period of time. They found that radium-226 concentrations increased when flowback water was being reused for additional fracking operations. Also, radium-226 tended to accumulate in the bottom sludge. This sludge could be classified as radioactive solid waste because it exceeded the radium-226 limit for landfill disposal. A risk assessment showed that potential radiation dose equivalent levels around the three fracking waste pits were within the regulatory limit for the general public.[354]

- April 9, 2015 – A Johns Hopkins Bloomberg School of Public Health study found that levels of radon in Pennsylvania homes—a region with some of the highest indoor radon concentrations in the US—have been rising since 2004, around the time the fracking industry arrived in the state.[355] Radon exposure is the second leading cause of lung cancer worldwide, after cigarette smoking.[356] Researchers found that buildings in counties where the most fracking has taken place in the past decade have had significantly higher radon readings compared with those in low-fracking areas, a difference that did not exist before 2004. Use of well water was associated with 21 percent higher indoor radon concentrations than in buildings using public water sources. This study, the first to define and evaluate the predictors of indoor radon concentrations in Pennsylvania, concluded that radon's presence was related to geology, water sources, weather, and natural gas drilling.[357]

- April 2, 2015 – A team of toxicologists, geochemists, and radiation scientists led by the University of Iowa analyzed the contribution of various naturally occurring radioactive materials (NORM) to the total radioactivity of fracking waste fluids, finding evidence of long-lived, environmentally persistent radioactive decay products.[358] "NORM is emerging as a contaminant of concern in hydraulic fracturing/unconventional drilling wastes, yet the extent of the hazard is currently unknown." The study determined that previous testing and study methods likely underestimate radioactivity by focusing only on radium. The researchers developed a new method to accurately predict the concentrations of uranium, thorium, and radium and their alpha-emitting progeny, polonium and lead, in fracking wastewater. They found that, under certain conditions,

[354] Zhang, T., Hammock, R. W., & Vidic, R. D. (2015). Fate of radium in Marcellus Shale flowback water impoundments and assessment of associated health risks. *Environmental Science & Technology 49*, 9347-54. doi: 10.1021/acs.est.5b01393

[355] Casey, J. A., Ogburn, E. L., Rasmussen, S. G., Irving, J. K., Pollak, J., Locke, P. A., & Schwartz, B. S. (2015). Predictors of indoor radon concentrations in Pennsylvania, 1989-2013. *Environmental Health Perspectives*. Advance online publication. doi: 10.1289/ehp.

[356] National Cancer Institute (2011, December 6). Radon and cancer fact sheet. Retrieved from http://www.cancer.gov/about-cancer/causes-prevention/risk/substances/radon/radon-fact-sheet

[357] Hurdle, J. & Phillips, S. (2015, April 9). New study raises possible link between gas drilling and radon levels. *StateImpact Pennsylvania.* Retrieved from http://stateimpact.npr.org/pennsylvania/2015/04/09/new-study-raises-possible-link-between-gas-drilling-and-radon-levels/

[358] Nelson, A. W., Eitrheim, E. S., Knight, A. W., May, D., Mehrhoff, M. A., Shannon, R., . . . Schultz, M.K. (2015). Understanding the radioactive in growth and decay of naturally occurring radioactive materials in the environment: An analysis of produced fluids from the Marcellus Shale. *Environmental Health Perspectives, 123*(7). doi: 10.1289/ehp.1408855

radioactivity increased over time, due to ingrowth of alpha-emitting radioactive progeny of long-lived parent radionuclides such as radium. The authors warned that these decay products may potentially contaminate recreational, agricultural, and residential areas, and that a more detailed understanding is needed of how radionuclides accumulate in higher organisms. In an accompanying article in *Environmental Health Perspectives*, James Burch, a University of South Carolina epidemiologist who was not involved in the study, said that fracking activities and wastewater disposal, which often take place in close proximity to where people live and work, raise risks for human exposure. "The technology is vastly outpacing what we know about the health effects."[359]

- May 8, 2014 – A group of leading medical experts and the American Lung Association of the Northeast detailed research and growing concerns about potential health impacts of radon and radium associated with natural gas production and the Marcellus Shale, in particular. High levels of radiation in the Marcellus Shale could pose health threats if high concentrations of radon and its decay products travel with natural gas, a problem compounded by the short distance Marcellus gas could travel in pipelines to people's homes.[360]

- March 24, 2014 – A team led by toxicology researchers at the University of Iowa identified high levels of radioactivity in fracking wastewater as a significant concern and noted that the testing methods used and recommended by state regulators in the Marcellus Shale region can dramatically underestimate the amount of radioactivity—specifically radium—in fracking wastewater.[361] Results obtained using EPA-recommended protocols can be obscured by the presence of other contaminant mixtures. Regarding the use of EPA protocols with fracking wastewater or other highly saline solutions, Duke University geochemist Avner Vengosh noted, "People have to know that this EPA method is not updated."[362]

- February 2014 – The Marcellus Shale is known to have high uranium and radium content. According to Mark Engle, USGS geochemist, the concentration of radium-226 can exceed 10,000 picoCuries/Liter (pCi/L) in the shale. Radium-226 has a half-life of 1,600 years. Radium and other naturally occurring radioactive materials (NORM) can be released from shale rock during drilling and fracking and can emerge with flowback and produced waters. It can thus enter the ambient environment and become concentrated in the sludge that results from treatment of flowback water, and in river sediment around water treatment facilities. It can also be found in landfills in which sludge and sediment

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[359] Konkel, L. (2015). What's NORMal for fracking? Estimating total radioactivity for produced fluids. *Environmental Health Perspectives, 123*(7). Retrieved from http://ehp.niehs.nih.gov/123-a186/

[360] Campbell, J. (2014, May 8). Fracking critics keep pushing for state-backed health study. *Politics on the Hudson*. Retrieved from http://polhudson.lohudblogs.com/2014/05/08/fracking-critics-keep-pushing-state-backed-health-study/

[361] Nelson, A. W., May, D., Knight, A. W., Eitrheim, E. S., Mehrhoff, M., Shannon, R., . . . Schultz, M. K. (2014). Matrix complications in the determination of radium levels in hydraulic fracturing flowback water from Marcellus shale. *Environmental Science & Technology, 1*(3), 204-208. doi: 10.1021/ez5000379

[362] Kelly, S. (2014, March 24). Research shows some test methods miss 99 percent of radium in fracking waste. *Desmogblog.com*. Retrieved from http://www.desmogblog.com/2014/03/23/some-testing-methods-can-miss-99-percent-radium-fracking-waste-new-research-reports

have been disposed. Some radium can be found in drinking water. Geochemist Avner Vengosh warned, "Once you have a release of fracking fluid into the environment, you end up with a radioactive legacy."[363]

- October 2, 2013 – A peer-reviewed study of the impacts of drilling wastewater treated and discharged into a creek by a wastewater facility in western Pennsylvania documented radium levels approximately 200 times greater in sediment samples near the discharge location than in sediment samples collected upstream of the plant or elsewhere in western Pennsylvania. "The absolute levels that we found are much higher than what you allow in the U.S. for any place to dump radioactive material," one of the authors told *Bloomberg News.* The pollution occurred despite the fact that the treatment plant removed a substantial amount of the radium from the drilling wastewater before discharging it. The researchers wrote that the accumulation of radium in sludge removed from the wastewater "could pose significant exposure risks if not properly managed."[364, 365]

- February 2013 – In an analysis of fracking sludge samples from Pennsylvania, researchers "… confirmed the presence of alpha, beta, and gamma radiation in the soil and water in reserve pits located on agricultural land." Total beta radiation exceeded regulatory guideline values by more than 800 percent, and elevated levels of some of the radioactive constituents remained in a vacated pit that had been drained and leveled. It is imperative, the research team concluded, "that we obtain better knowledge of the quantity of radioactive material and the specific radioisotopes being brought to the earth's surface from these mining processes."[366]

- July 26, 2012 – Responding to concern about radon in natural gas produced from the Marcellus Shale, the USGS analyzed ten samples of gas collected near the wellheads of three Pennsylvania gas wells. The agency found radon levels ranging from 1-79 picocuries per liter, with an average of 36 and a median of 32. (The highest radon activity reported here would decay to 19.8 pCi/L in approximately a week; by comparison, the EPA's threshold for indoor air remediation is 4 pCi/L.) Asserting they knew of no previous published measurements of radon in natural gas from the Appalachian Basin, which contains the Marcellus Shale, agency scientists concluded that the number of

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[363] Brown V. J. (Feb 2014). Radionuclides in fracking wastewater. *Environmental Health Perspectives 122*(2), A50-A55. doi: 10.1289/ehp.122-A50

[364] Warner, N. R., Christie, C. A., Jackson, R. B., & Vengosh, A. (2013). Impacts of shale gas wastewater disposal on water quality in Western Pennsylvania. *Environmental Science & Technology, 47*(20), 11849-11857. doi: 10.1021/es402165b

[365] Efstathiou, J., Jr. (2013, October 2). Radiation in Pennsylvania creek seen as legacy of fracking. *Bloomberg*. Retrieved from http://www.bloomberg.com/news/2013-10-02/radiation-in-pennsylvania-creek-seen-as-legacy-of-frackin.html

[366] Rich, A. L., & Crosby, E. C. (2013). Analysis of reserve pit sludge from unconventional natural gas hydraulic fracturing and drilling operations for the presence of technologically enhanced naturally occurring radioactive material (TENORM). *NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy, 23*(1), 117-135. doi: 10.2190/NS.23.1.h

samples "is too small to … yield statistically valid results" and urged "collection and interpretation of additional data."[367]

- January 11, 2012 – In its review of the New York State Department of Environmental Conservation's (NYS DEC) Supplemental Generic Environmental Impact Statement (SGEIS) on high volume fracturing, the EPA expressed concerns about the diffusion of responsibility for the ultimate disposal of radioactive wastes generated by treatment or pretreatment of drilling wastewater. The EPA also raised concerns about the lack of analysis of radon and other radiation exposure. "Who is responsible for addressing the potential health and safety issues and associated monitoring related to external radiation and the inhalation of radon and its decay products?" the EPA asked. "Such potential concerns need to be addressed."[368]

- September 7, 2011 – The USGS reported that radium levels in wastewater from oil and gas wells in New York and Pennsylvania, including those in the Marcellus Shale, "have a distinctly higher median … than reported for other formations in the Appalachian Basin, and range to higher values than reported in other basins." The median level of radium found in Marcellus Shale wastewater in New York, 5,490 pCi/L, is almost 1,100 times the maximum contaminant level for drinking water, which is five pCi/L. In other words, if a million gallons of Marcellus Shale wastewater contaminated with the median level of radium found in New York were to spill into a waterway, 1.1 billion gallons of water would be required to dilute the radium to the maximum legal level.[369] (The EPA's health-based goal for radium in drinking water is zero.) Over time, radium naturally decays into radioactive radon gas. Thus, higher radium levels also suggest that higher levels of radon may also be present in natural gas produced from the Marcellus Shale.

- February 27, 2011 – The *New York Times* reported on the threat to New York's drinking water from Pennsylvania drilling waste due to the presence of chemical contaminants, including high levels of radioactivity. The investigation found that sewage treatment plants were neither testing for nor capable of removing that radioactivity, which was subsequently discharged into waterways that supply drinking water, and that, in some cases, wastewater contained radium levels that were hundreds of times higher than the drinking water standard. Drillers sent some of this waste to New York State for disposal even though, as the article noted, EPA scientists had warned the state about this very problem in a December 2009 letter that advised against sewage treatment plants

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[367] Rowan, E. L., & Kraemer, T. F. (2012). *Radon - 222 content of natural gas samples from upper and middle Devonian sandstone and shale reservoirs in Pennsylvania: Preliminary data*. United States Geological Survey. (Rep.). Retrieved from http://pubs.usgs.gov/of/2012/1159/ofr2012-1159.pdf

[368] Environmental Protection Agency. (2012, January 11). *EPA comments on revised draft NYSDEC revised dSGEIS for horizontal drilling and high-volume hydraulic fracturing to develop the Marcellus shale and other low-permeability gas reservoirs* [Press release]. Retrieved from http://www.epa.gov/region2/newsevents/pdf/EPA%20R2%20Comments%20Revised%20dSGEIS%20Enclosure.pdf

[369] Rowan, E. L., Engle, M. A., Kirby, C. S., & Kraemer, T. F. (2011, September 7). *Radium content of oil- and gas-field produced waters in the northern Appalachian basin (USA): Summary and discussion of data*. (Rep United States Geological Survey. Retrieved from http://pubs.usgs.gov/sir/2011/5135/ http://water.epa.gov/drink/contaminants/basicinformation/radionuclides.cfm

accepting drilling waste with radium levels 12 or more times as high as the drinking water standard.[370]

- 2008-2009 – The New York State DEC found that wastewater from 11 of 13 vertical wells drilled in New York's Marcellus Shale in 2008 and 2009 contained radium levels ranging from 400 times to nearly 3,400 times EPA's safe levellimit for radium in drinking water. These figures later informed the 2011 study of radium in drilling wastewater conducted by the USGS.[371]

Occupational health and safety hazards

Drilling and fracking jobs are among the most dangerous jobs in the nation with a fatality rate that is four to seven times the national average. Irregularities in reporting practices mean that counts of on-the-job fatalities among oil and gas workers are likely underestimates. Contract workers are especially at risk; the majority of those killed by fatal falls in oil and gas extraction from 2003–2013 worked for contractors. Occupational hazards include head injuries, traffic accidents, blunt trauma, burns, inhalation of hydrocarbon vapors, toxic chemical exposures, heat exhaustion, dehydration, and sleep deprivation. An investigation of occupational exposures found high levels of benzene in the urine of well-pad workers, especially those in close proximity to flowback fluid coming up from wells following fracturing activities. Exposure to silica dust, which is definitively linked to silicosis and lung cancer, was singled out by the National Institute for Occupational Safety and Health as a particular threat to workers in fracking operations where silica sand is used. At the same time, research shows that many gas field workers, despite these serious occupational hazards, are uninsured or underinsured and lack access to basic medical care.

- December 6, 2017 – Two occupational fatalities and numerous injuries resulted from explosions and fires along oil and gas pipelines in Colorado in the time since two men were killed at home from such a blast in April 2016, according to a *Denver Post* investigation. One contract worker was killed and two others were injured in May while they "were changing 'dump lines' and 'one or more tanks exploded,' according to a report filed in [Colorado Oil and Gas Conservation Commission's] database." Another worker died of his burn injuries from a flash fire in November that broke out during work on a pipeline. "The COGCC did not receive a report on this incident… because the pipeline was a 'gathering line' outside the agency's regulatory purview." The

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[370] Urbina, I. (2011, February 26). Regulation lax as gas wells' tainted water hits rivers. *The New York Times*. Retrieved from http://www.nytimes.com/2011/02/27/us/27gas.html?pagewanted=all&_r=0

[371] New York State Department of Environmental Conservation. (2011). *Supplemental generic environmental impact statement on the oil, gas and solution mining regulatory program, well permit issuance for horizontal drilling and high-volume hydraulic fracturing to develop the Marcellus shale and other low-permeability gas reservoirs* (5-133, 5-141, 7-60, Appendix 12, Appendix 13, Rep.).

investigation documented additional gaps in regulatory oversight and responses to deaths and injuries.[372]

- October 1, 2017 – An investigation by the *Toronto Star*, the *National Observer*, *Global News*, and four Canadian journalism schools reported on hydrogen sulphide (H_2S)-related health threats and incidents (including one occupational death) in Saskatchewan, and government and industry failure to prevent, warn, and respond to this threat. The more than 50 reporters involved "examined thousands of industry and government documents, analyzed terabytes of data and delved into dozens of freedom-of-information requests," documenting, for example, the existence of government data describing H_2S "hotspots" across the province, that were never released to the public despite agency deliberations. In addition, reporters wrote,

  > Ministry and industry met four times between 2012 and 2014 to plot strategy, including emergency planning zones, a public communications document, a code of practice and a licensing regime for high-risk, single-well batteries. Those plans were never adopted, a ministry statement confirms.

  An industry salesman was killed in 2014 while taking samples. A valve broke and the concentration of H_2S in the spewed fluids, according to the company, "was estimated at 40,000 parts per million, more than enough to bring near-instant death." The investigation found that four months after the death, "a secret ministry report listed 161 facilities 'that may be in violation of (the ministry's) sour gas emission control.'"[373]

- May 30, 2017 – In a "rare, but not unprecedented" case, the U.S. Environmental Protection Agency (EPA) opened an investigation of air emissions from two North Dakota oil well sites where worker deaths occurred in 2012 and 2014. The EPA requested information from both companies to determine Clean Air Act compliance on the day of the deaths. According to the *E&E News* report, it was not clear whether the agency was "looking at civil or criminal sanctions." Both workers, who were "flow testers," "assigned to regularly measure tank levels by hand," were found dead near tank hatches.[374] [No further information could be located on this investigation.]

- April 28, 2017 – Fatality rates for oil and gas extraction workers associated with falls increased two percent per year during 2003–2013, according to the Centers for Disease Control and Prevention's *Morbidity and Mortality Weekly Report.* These 63 fatal falls represented 15 percent of the fatal events among this group in the time period. The majority of those who were killed by falls worked for drilling contractors. In the vast

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[372] Finley, B. (2017, December 6). A dozen fires and explosions at Colorado oil and gas facilities in 8 months since fatal blast in Firestone. *Denver Post.* Retrieved from http://www.denverpost.com/2017/12/06/colorado-oil-gas-explosions-since-firestone-explosion/

[373] Cribb, R., Sonntag, P., Elliot, P. W., & McSheffrey, E. (2017, October 1). That rotten stench in the air? It's the smell of deadly gas and secrecy. *Thestar.com*. Retrieved from https://www.thestar.com/news/canada/2017/10/01/that-rotten-stench-in-the-air-its-the-smell-of-deadly-gas-and-secrecy.html

[374] Soraghan, M. (2017, May 30). EPA investigating emissions in tank deaths. *E&E News.* Retrieved from https://www.eenews.net/stories/1060055258

majority of cases, "fall protection was required by regulation, but it was not used, was used improperly, or the equipment failed." Authors noted several limitations of their report, such as the lack of information on self-employed workers and lack of detail in some fatality reports.[375]

- April 26, 2017 – The 2017 edition of the AFL-CIO report, *Death on the Job: The Toll of Neglect*, which reported on the year 2015, showed that, although the number of deaths in the oil and gas extraction industries decreased compared to 2014 (89 compared to 144), employment in oil and gas extraction also decreased from 613,783 in 2014 to 533,184 in 2015. The deaths in the oil and gas extraction industries "accounted for 74% of the fatal work injuries in the mining sector." Referring to the challenges of getting a firm handle on statistics in this industry, the report stated that, "[f]atality rate data for the oil and gas industry are limited, but available data during the past seven years show fatality rates in oil and gas extraction that are four to seven times the national fatality rate." Further, "[n]ot surprisingly, states with large amounts of oil and gas activity also have high job fatality rates." Citing the continuing problem of assigning cause of death in the case of possible inhalation of toxic fumes, the report stated, "[w]hile some deaths are appropriately classified as inhalation deaths, others can be labeled as cardiac arrhythmia or respiratory failure, without further investigation as to whether the health event was induced by acute chemical exposure." As in previous years, the report expressed concerns about the regulatory gaps in controlling a range of potentially fatal hazards in the industry.[376]

- February 1, 2017 – University of Tennessee Civil and Environmental Engineering faculty investigated the occupational inhalation risks from the emissions of chemical storage tanks in 60,644 fracking wells. They also analyzed the combined occupational inhalation risks caused by open flowback pits and the storage tanks. They used AERMOD, the air pollution dispersion modeling system developed by the American Meteorological Society and EPA, and inhalation risk assessment to determine potential acute non-cancer, chronic non-cancer, acute cancer, and chronic cancer risks. Their results showed the percentage of wells presenting these risks were 12.41, 0.11, 7.53, and 5.80, respectively. They also found that the storage tanks presented the majority of the cancer risks, and the non-cancer risks were associated primarily to the open pits. The known human carcinogen formaldehyde was "the dominant contributor" to both acute (4,267 wells) and chronic (3,470 wells) cancer risk. Authors also reported that volatile organic compound (VOC) emissions from nearby wells and other on-site sources means that the data used in their study "were lower than reported concentrations from field measurements where higher occupational inhalation risks for exposure may be expected." [377]

[375] Mason, K. L., Retzer, K. D., Hill, R., & Lincoln, J. M. (2017). Occupational fatalities resulting from falls in the oil and gas extraction industry, United States, 2005–2014. *MMWR, 66*(16), 417–421. doi: http://dx.doi.org/10.15585/mmwr.mm6616a2
[376] AFL-CIO. (2016). Death on the job: The toll of neglect. Retrieved from https://aflcio.org/reports/death-job-toll-neglect-2017
[377] Chen, H., & Carter, K. E. (2017). Modeling potential occupational inhalation exposures and associated risks of toxic organics from chemical storage tanks used in hydraulic fracturing using AERMOD. *Environmental Pollution, 224*, 300-309. doi: 10.1016/j.envpol.2017.02.008

- January 19, 2017 – A group of Canadian physicians published a report documenting ten intentional intoxications from the ingestion of fracking fluid. Each individual survived, which the authors attribute to "[r]apid case finding and diligent contact tracing." Their report, published in the *American Journal of Kidney Diseases,* focused on this appropriate response and treatment, but also described the "outbreak" challenge from a public health perspective and emphasized the need for prevention education and "requiring secure storage of these products." Though the professions or workplaces of the patients are not described, presumably they were oil and gas industry workers with easy access to fracking fluid.[378]

- September 25, 2016 – A four-chapter investigative series by the *Denver Post* explored in detail Colorado's 12-year record of an oil and gas worker dying, on average, every three months. The piece documented the obstacles present in even clarifying the occupational mortalities owing to the differing reporting practices of the Bureau of Labor Statistics, OSHA, and state officials. "Regulation is so disjointed that no one can even agree on the number of workers killed on the job." Investigating the details of the deaths through any available records, the *Post* described a "regulatory vacuum," as well as "little consequence" to the industry when deaths (or worksite violations) occur. Worker death circumstances examined in the piece included electrocutions, falls and collapsed structures, crushings by equipment, explosions, and a drowning in frack sand. The *Post* also identified five lawsuits over 15 years "in which workers alleged that they were punished for reporting injuries or safety hazards."[379]

- April 27, 2016 – According to the 2016 edition of the AFL-CIO report, *Death on the Job: The Toll of Neglect,* the fatality rate for workers in the oil and gas extraction industries is nearly five times the national average, and the states with prominent oil and gas industries are among the most dangerous states to work. In addition, the report emphasized, the industry has been exempted from some critical Occupational Safety and Health Administration (OSHA) standards, including that for carcinogenic benzene. The report also emphasized the danger of silica dust exposure in hydraulic fracturing-related work and the significant delays in controlling workers' exposures in these operations. "Oil and gas extraction is subject to OSHA general industry and construction regulations, none of which are designed to address the particular safety and hazards in the oil and gas industry…. The escalating fatalities and injuries in the oil and gas extraction industry demand intensive and comprehensive intervention," the report stated.[380]

- April 21, 2016 – According to an updated report from the Bureau of Labor Statistics, fatal work injuries in oil and gas extraction industries in 2014 reached a new high of

[378] Collister, D., Duff, G., Palatnick, W., Komenda, P., Tangri, N., & Hingwala, J. (2017). A methanol intoxication outbreak from recreational ingestion of fracking fluid. *American Journal of Kidney Diseases, 69*(5), 696-700. doi: 10.1053/j.ajkd.2016.10.029
[379] Sangosti, R.J. (2016, September 25). Drilling through danger. *Denver Post.* Retrieved from http://extras.denverpost.com/oil-gas-deaths/index.html
[380] AFL-CIO. (2016). Death on the job: The toll of neglect. Retrieved from http://www.aflcio.org/Issues/Job-Safety/Death-on-the-Job-Report

144.[381] The final 2015 data are scheduled for release on December 16, 2016.

- February 29, 2016 – *Inside Energy's* report on high rates of hydrocarbon vapor poisoning among oilfield workers noted that an outdated reliance on manual measurements rather than automated monitoring contributes to ongoing toxic exposures of workers. Under federal oil and gas regulations, oil companies are effectively required to send workers "up on oil and gas tanks to manually measure crude oil, putting them at risk." The report explained that the Bureau of Land Management (BLM) allows just one kind of automated measurement. The method is expensive and uncommonly used: "there are only 1,500 in use, compared to more than 83,000 oil tanks on federal land. By being so inflexible, BLM's outdated rules make it very hard to use safer oil measuring devices while making manual oil tank measurement—which endangers workers—the most viable option for companies."[382]

- February 19, 2016 – The fatal injuries of a backhoe operator who struck and hit an unmarked, high-pressure gas line in July 2015 prompted an investigation by *StateImpact* in Pennsylvania. The news group noted that "there are no local, state or federal rules on how deep the lines should be buried underground, or even if they're buried at all. There are no standards for building and maintaining the lines. They don't have to be marked. And the operator of the line doesn't have to participate in PA One Call [a statewide communications system for preventing damage to underground facilities], which led to the fatality in Armstrong County."[383]

- January 15, 2016 – In a publication in Centers for Disease Control's *Mortality & Morbidity Weekly Report*, researchers urged local and state epidemiologists and medical examiners to not overlook hydrocarbon exposure as an underlying cause of death in gas and oil field workers. "Health and safety professionals need to recognize and act on nonfatal warning signs and symptoms, such as dizziness, confusion, immobility and collapse in oil and gas workers who might have been exposed to high concentrations of [hydrocarbon gas vapors] and to [oxygen]-deficient atmospheres." Only three of nine deaths that occurred between 2010 and 2015 in the oil and gas fields west of Appalachia were ruled by coroners to have resulted from exposure to gas vapors, although all nine had opened hatches of storage tanks and were exposed to hydrocarbon vapors and oxygen-deficient air.[384] The *Pittsburgh Post-Gazette* quoted emeritus professor at the University of Pittsburgh Bernard Goldstein saying, "Occupational health experts also

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[381] U.S. Bureau of Labor Statistics. (2016, April 21). Revisions to the 2014 Census of Fatal Occupational Injuries (CFOI). Retrieved from http://www.bls.gov/iif/cfoi_revised14.htm
[382] Guerin, E. (2016, February 29). "Senseless exposures": How money and federal rules endanger oilfield workers. *Inside Energy*. Retrieved from http://insideenergy.org/2016/02/29/senseless-exposures-how-money-and-federal-rules-endanger-oilfield-workers/
[383] Phillips, S. (2016, February 19). Worker dies in pipeline accident, PUC steps up calls for reform. *StateImpact.* Retrieved from https://stateimpact.npr.org/pennsylvania/2016/02/19/worker-dies-in-pipeline-accident-puc-steps-up-calls-for-reform/
[384] Harrison, R. J., Retzer, K., Kosnett, M. J., Hodgson, M., Jordan, T., Ridl, S., & Kiefer, M. (2016). Sudden deaths among oil and gas extraction workers resulting from oxygen deficiency and inhalation of hydrocarbon gases and vapors — United States, January 2010–March 2015. *Morbity and Mortality Weekly Report, 65*(1), 6-9. Retrieved from http://www.cdc.gov/mmwr/volumes/65/wr/mm6501a2.htm

suspect that some deaths involving fires, falls, crashes and mishandling of equipment have resulted from faulty judgement or 'wooziness' associated with hydrocarbon vapor exposure … [b]ut that underlying factor rarely shows up in fatality reports."[385]

- December 14, 2015 – As reported in the *Guardian*, the suicide rate in the Canadian province of Alberta spiked by 30 percent spike in the first half of 2015, possibly linked to the boom-and-bust cycle of the fracking industry. At the time of reporting, 40,000 jobs had been lost in Alberta since the drop in oil prices in late 2014. Mental health professionals interviewed for the report included Edmonton social worker Leonard McEwan, who specializes in clinical crises intervention and whose patients include those directly or indirectly employed in the oil fields, noticed a sharp increase in suicides after the recent plunge in oil prices. As revealed in the investigative report, three in every four Alberta suicides are male and the vast majority are under 55. Gladys Blackmore, executive director of a mental health program that targets those employed in the industry, believes that young, male workers "living high-risk lifestyles, often in work camps, where they 'fly-in/fly-out' for up to 24 days at a time" are particularly vulnerable.[386]

- November 7, 2015 – The *Denver Post* reported on a "new federal database that was developed to more precisely capture the deadly nature of oil and gas extraction." For Colorado, the national Fatalities in Oil and Gas Extraction (FOG) database contained two additional oil and gas worker deaths for 2014 than did the Bureau of Labor Statistics. "'We knew from the Bureau of Labor Statistics data about the basics of what's killing workers,' said Kyla Retzer, an epidemiologist who led the effort to compile the FOG report. 'We just wanted to be more in-depth in finding out what were the types of operations and equipment were involved in these deaths.'"[387]

- November 4, 2015 – San Antonio's *Express-News* Editorial Board called for specific actions to address Texas's status "a national leader in oil field deaths." The Board wrote that federal fines are too low and unchanged since 1991 and that there is no Level 1 trauma center south of San Antonio near the region's oil- and gas-producing counties.[388]

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[385] Litvak, A. (2016, January 25). Vapors linked to oxygen depletion present hazard for oil, gas workers. *Pittsburgh Post-Gazette.* Retrieved from http://powersource.post-gazette.com/powersource/policy-powersource/2016/01/25/Vapors-linked-to-oxygen-depletion-present-hazard-for-oil-gas-workers/stories/201601220095

[386] Mouallem, O. (2015, December 14). The boom, the bust, the darkness: suicide rate soars in wake of Canada's oil crisis. *The Guardian*. Retrieved from https://www.theguardian.com/world/2015/dec/14/canada-oil-production-crisis-suicide-alberta?CMP=share_btn_fb

[387] Whaley, M. (2015, November 7). Colorado oil deaths greater in 2014 than previously calculated. *Denver Post.* Retrieved from http://www.denverpost.com/2015/11/07/colorado-oil-deaths-greater-in-2014-than-previously-calculated/

[388] *Express-News* Editorial Board. (2015, November 4). Take care of the state's oil, gas workers. *MySanAntonio.Com.* Retrieved from http://www.mysanantonio.com/opinion/editorials/article/Take-care-of-the-state-s-oil-gas-workers-6611077.php

- September 17, 2015 – The Bureau of Labor Statistic reported that the number of fatal work injuries in oil and gas extraction industries rose 27 percent between 2013 and 2014.[389]

- September 15, 2015 – E&E Publishing's *EnergyWire* reported on the potentially deadly risk of exposure to vapors from oil and gas field storage tanks, including deaths that were officially attributed to cardiac arrest, though inhalation of toxic gases and lack of oxygen played a role, as demonstrated in subsequent litigation. The reporter gave detail on the circumstances of several of the deaths, including that of a long-haul trucker who had heart disease and was diabetic, and whose death was classified as natural. "But he didn't suffer a heart attack that day, or a diabetic episode. Medical experts said he likely wouldn't have died outside the toxic atmosphere on the catwalk." A Denver cardiologist testified that "there was no other reason for him to have died that day."[390] (NIOSH has subsequently targeted outreach to medical examiners to improve their recognition of this hazard and potential cause of death; see above.)

- September 5, 2015 – In partnership with Rocky Mountain PBS I-News, *The Durango Herald* reported on the oil and gas industry's varied practices in their handling of silica sand with regard to worker protection. In 2012 the National Institute for Occupational Safety and Health issued an alert concerning workers at fracking sites being exposed to silica dust at levels that exceeded occupational exposure limits. Industry has resisted updates to the standards. The *Herald* report addressed technological and work practice controls to reduce exposure on the part of some companies. Still, authors wrote, silicosis "can hide for a decade before causing symptoms. No one knows how many oil and gas workers may have already been exposed."[391]

- June 29, 2015 – An investigation by the Center for Public Integrity (CPI) found that lung-damaging silica is not sufficiently regulated to prevent silicosis (which is incurable and has no effective treatment) or lung cancer in the workplace. Rules governing occupational exposure to silica dust are far outdated, and advocacy efforts to tighten them are four decades old. At particular risk, say the authors, are workers in oil and gas fields where silica sand is used in fracking operations. Citing research by NIOSH, the CPI team noted that nearly 80 percent of the air samples on the well pads were above the recommended exposure limit for silica dust.[392]

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[389] U.S. Department of Labor, Bureau of Labor Statistics (2015, September 17). National census of fatal occupational injuries in 2014 (preliminary results). USDL-15-1789. Retrieved from http://www.bls.gov/news.release/pdf/cfoi.pdf

[390] Soraghan, B. (2015, September 14). SAFETY: How shale oil can kill. *E&E Publishing, LLC*. Retrieved from http://www.eenews.net/stories/1060024589

[391] Boiko-Weyrauch, A. (2015, September 5). Oil, gas industry responding to threat of worker lung disease. *Durango Herald.* Retrieved from http://www.durangoherald.com/article/20150905/NEWS02/150909741/Oil-gas-industry-responding-to-threat-of-worker-lung-disease-

[392] Morris, J., Hopkins, J. S., & Jameel, M. (2015, June 30). Unequal risk: Slow-motion tragedy for American workers. *The Center for Public Integrity.* Retrieved from http://www.publicintegrity.org/2015/06/29/17518/slow-motion-tragedy-american-workers

- June 15, 2015 – *EnergyWire* examined issues surrounding exposure to crystalline silica from frack sand mining, which is a health concern to those living near mines and to those working in the industry. Families living near industrial sand mining reported that their health has been compromised by sand mine development and are concerned that companies are not properly monitoring their extraction sites. The article noted that the Occupational Safety & Health Administration (OSHA) is working on a new exposure rule for workers that OSHA estimates would save nearly 700 lives and prevent 1,600 new cases of silicosis annually. The oil and gas industry is fighting the rule because of the cost associated with complying with a more stringent permissible exposure limit. Crispin Pierce, public health researcher at the University of Wisconsin in Eau Claire, is in the midst of a three-pronged research project to look at the industry's air effects. Among other findings, his project's air monitors around sand plants have found consistently finding higher readings than the Wisconsin Department of Natural Resources' reported regional values.[393]

- June 15, 2015 – In an update, NIOSH noted that silicosis death rates are rising again, reversing an earlier, decade-long decline. In the list of job tasks with known high silica exposures, the update named hydraulic fracturing of gas and oil wells. These results are particularly concerning in light of earlier research showing significant under-detection of silicosis among deceased workers with known exposure to silica dust.[394]

- June 13, 2015 – Reporting on North Dakota's fracking boom, the Center for Investigative Reporting found that the major oil companies have largely written the rules governing their own accountability for accidents. Deeply entrenched corporate practices and weak federal oversight, according to the report, have led to high injury and death rates and a shift of assigned responsibility to others. Using data from U.S. and Canadian regulators, the journalists verified 74 on-the-job deaths among workers in Bakken Shale drilling and fracking operations since 2006. The actual number of deaths is likely higher than currently reported because federal regulators do not have a systematic way to record oil- and gas-related deaths, and OSHA does not include certain fatalities, including those of independent contractors. The report concluded that there was too little oversight from OSHA, that laws to protect workers were outdated, and that there was a culture of self-regulation by the industry.[395]

- May 29, 2015 – The Centers for Disease Control and Prevention published statistics on work-related fatalities during the fracking boom. The occupational fatality rate among U.S. oil and gas industry extraction workers between 2003 and 2013 remained an average of seven times higher than among U.S. workers in general (25.1 versus 3.7 deaths per 100,000 workers per year). Within this 11-year period, the industry doubled the size of its

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[393] King, P. (2015, June 15). Frac sand towns question whether rules protect them against silica pollution. *EnergyWire.* Retrieved from http://www.eenews.net/stories/1060020192
[394] Mazurek, J. M. & Weissman, D. (2015, June 15). Silicosis update. *NIOSH Science Blog*. Retrieved from http://blogs.cdc.gov/niosh-science-blog/2015/06/15/silicosis-update/
[395] Gollan, J. (2015, June 13). In North Dakota's Bakken oil boom there will be blood. *Reveal; Center for Investigative Reporting.* Retrieved from https://www.revealnews.org/article/in-north-dakotas-bakken-oil-boom-there-will-be-blood/

workforce and increased drilling rigs by 71 percent. The number of occupational deaths increased 27.6 percent, with a total of 1,189 deaths, but it did not increase as much as the number of workers, resulting in an overall decrease in the fatality rate of 36.3 percent. Transportation accidents and contact with objects and equipment were the most frequent fatal events. Evidence suggests that the increased use of automated technologies on drilling rigs may be contributing to the decline in death rates.[396]

- April 22, 2015 – The AFL-CIO published data for job injuries, illnesses and deaths in a national and state-by-state profile of worker safety and health in the United States, presenting comparisons by state and industry. For the third year in a row, North Dakota had the highest on-the-job fatality rate in the nation: 14.9 deaths per 100,000 workers, a rate that is more than four times the national average, and which has more than doubled since 2007. The fatality rate in the mining and oil and gas extraction sector in North Dakota was 84.7 per 100,000, which is nearly seven times the national fatality rate of 12.4 per 100,000 in this industry.[397, 398]

- April 10, 2015 – In a study that was inclusive of fracking-based extraction but not specific to it, NIOSH researchers updated their investigation into the sudden deaths of nine oil and gas extraction workers found near hatches where hydrocarbons were stored. All nine victims died between 2010 and 2014 and were unobserved or working alone at the time of their deaths. The first report attributed the fatalities to "inhalation of volatile petroleum hydrocarbons."[399] The update noted that when workers open hatches on production tanks, a plume of hydrocarbon gases and vapors can be rapidly released due to high internal pressure. Exposure to high concentrations of these low-molecular-weight hydrocarbons creates asphyxiation and explosive hazards and can have narcotic effects, resulting in disorientation, dizziness, and light-headedness. The authors cited reports of other sudden deaths following butane and propane inhalation, exposure to which can induce irregular heartbeat, insufficient oxygen supply, and respiratory depression.[400] As reported by the *Denver Post*, most of the death certificates listed natural causes or heart failure as the cause likely because medical examiners can easily miss signs of toxic inhalation during a routine autopsy. The nomadic nature of the industry presents obstacles to proper training in tank handling techniques.[401] NIOSH issued

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[396] Mason, K. L., Retzer, K. D., Hill, R., & Lincoln, J. M. (2015, May 29). Occupational fatalities during the oil and gas boom—United States, 2003-2013. *Morbidity and Mortality Weekly Report, 64,* 551-554. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6420a4.htm

[397] AFL-CIO Safety and Health Department, (2015, April 22). Death on the job: The toll of neglect. Retrieved from http://www.aflcio.org/Issues/Job-Safety/Death-on-the-Job-Report

[398] Kasperkevic, J. (2015, April 29). About 150 US workers are killed on the job every day – report. *Guardian.* Retrieved from http://www.theguardian.com/us-news/2015/apr/29/north-dakota-deadliest-state-workers-third-year-running

[399] NIOSH. (2015, March 15). Suspected inhalation fatalities involving workers during manual tank gauging, sampling, and fluid transfer operations on oil and gas well sites, 2010-2014. *CDC Workplace Safety & Health Topics*. Retrieved from http://www.cdc.gov/niosh/topics/fog/data.html#_ftn1

[400] King, B., Esswein, E., Retzer, K., Snawder, J., Ridl, S., Breitenstein, M. Alexander-Scott, M., & Hill, R. (2015, April 10*). NIOSH Science Blog*, Centers for Disease Control. Retrieved from http://blogs.cdc.gov/niosh-science-blog/2015/04/10/flowback-3/

[401] Whaley, M. (2015, May 18). Toxic vapors suspected in deaths of three Colorado oil and gas workers. *Denver Post.* Retrieved from http://www.denverpost.com/news/ci_28136543/colorado-oil-and-gas-workers-fell-victim-little

recommendations for worker protections, including respiratory protection training and engineering controls for remote gauging and venting.[402]

- February 15, 2015 – Burn injuries among North Dakota workers surged to more than 3,100 over the past five years as the area has become the epicenter of a massive drilling and fracking boom, as reported by the *Star Tribune*. Despite the flammability of Bakken crude oil and the danger of oil rig work, North Dakota has no burn centers, and burn victims must be transported out of state, typically to the Minneapolis-St. Paul area some 600 miles away. The article also covered the severe, debilitating, costly, and sometimes fatal aspects of these occupational injuries.[403]

- February 13, 2015 – NIOSH reported that while silicosis death rates declined between 2001 and 2010, silicosis deaths were still occurring among young persons aged 15 to 44 years old, indicating extremely high exposures to respirable silica dust. Among emerging new settings that put workers at risk for silicosis, the authors named oil and gas extraction industry workers.[404]

- January 14, 2015 – The *Charleston Gazette-Mail* reported that, due to an increase in workplace deaths that has accompanied the boom in natural gas drilling and production from the Marcellus Shale fields in Northern West Virginia, the Governor there has called for a study aimed at reversing that trend. "Between 2009 and 2013, as the industry boomed in the Marcellus region, 15 natural gas workers died on the job in West Virginia, according to the federal data. During the previous five-year period, from 2004 to 2008, three workers died in West Virginia's oil and gas industry, according to the [U.S. Bureau of Labor Statistics]."[405]

- January 12, 2015 – Oil and gas production employs less than one percent of the U.S. workforce, but in the past five years it has had more than ten percent of all workplace fatalities from fires and explosions. A review by *EnergyWire* of federal labor statistics last year found the industry had more deaths from fires and explosions than any other private industry. The only "industry" with more fire and explosion fatalities than oil and gas was firefighting, the report stated. These statistics are inclusive of deaths related to fracking operations but are not specific to them.[406]

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[402] Associated Press. (2015, May 18). 9 oil well deaths lead to warning about inhaling chemicals. *Times-Call.* Retrieved from http://www.timescall.com/news/nationworldnews/ci_28138297/9-oil-well-deaths-lead-warning-about-inhaling

[403] Rao, M. (2015, February 15). Twin Cities hospitals are front line in treating Bakken burn victims. StarTribune.com. Retrieved from http://www.startribune.com/lifestyle/health/291967611.htmlpage=all&prepage=1&c=y#continue

[404] Bang, K. M., Mazurek, J. M., Wood, J. M., White, G. E., Hendricks, S. A., & Weston, A. (2015), Silicosis mortality trends and new exposures to respirable crystalline silica – United States, 2001-2010. *Morbidity and Mortality Weekly Report, 64*(05), 117-120. Retrieved from http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6405a1.htm

[405] Ward, K. (2015, January 14). Tomblin calls for study of increased deaths from gas-drilling boom. *Charleston Gazette*. Retrieved from http://www.wvgazette.com/article/20150114/GZ01/150119573/1419

[406] Soraghan, M. (2015, January 12). At least 16 drilling industry workers died in fires, explosions last year. *EnergyWire.* Retrieved from http://www.eenews.net/stories/1060011452

- December 26, 2014 – A report in the *Houston Chronicle* illustrated the difficulties oil and gas workers encounter when injured on the job. In one case a worker fell from a rig, injuring his head. Supervisors did not record the accident. After he became too ill to work, he was shifted to other jobs and soon after, sent home. His daughter filed a Worker's Compensation claim, which was denied for "late reporting, no knowledge of injury by employer and no medical reports." The article noted that oilfield injuries are generally undercounted nationally. These include injuries related to drilling and fracking operations as well as those linked to other techniques of extraction.[407]

- December 4, 2014 – Benzene, a naturally occurring component of crude oil and natural gas, is a known carcinogen, with no known threshold of safety. Although the American Petroleum Institute in 1948 stated that "the only absolutely safe concentration … is zero," the organization since then undertook an intensive campaign to combat strict exposure limits. An investigation by the Center for Public Integrity found that, "[f]or decades, the petrochemical industry spent millions on science seeking to minimize the dangers of benzene. … Taken together, the documents—put in context by interviews with dozens of lawyers, scientists, academics, regulators and industry representatives—depict a 'research strategy' built on dubious motives, close corporate oversight and painstaking public relations."[408]

- December, 2014 – In a report intended to inform employers and workers about the known hazards that result from hydraulic fracturing and flowback operations, OSHA noted that there is no publicly available worker injury, illness, or fatality data specific for fracking or flowback operations. At the same time, more workers are exposed to fracking- and flowback-related hazards due to the huge increase in the numbers of these operations over the past ten years. "In light of this, OSHA has determined that additional information concerning hydraulic fracturing and flowback operations hazards should be provided to educate and protect workers."[409]

- November 11, 2014 – University of Wisconsin toxicologist Crispin Pierce documented super-fine dust drifting from facilities that process silica sand for fracking operations. Pierce and his team detected silica dust in ambient air near frac sand operations at levels that exceed EPA air quality standards by a factor of four. Occupational exposure to respirable crystalline silica is linked in adult workers to silicosis, lung cancer, and pulmonary tuberculosis. Health threats to the general public from frac sand-related air pollution have not yet been studied directly. One of the first investigations of silica dust

[407] Olsen, L. (2014, December 16). Many oilfield injuries go unreported. *Houston Chronicle.* Retrieved from http://www.houstonchronicle.com/news/houston-texas/houston/article/Many-oilfield-injuries-go-unreported-5980350.php
[408] Lombardi, K. (2014, December 4). Benzene and worker cancers: 'An American tragedy.' The Center for Public Integrity. Retrieved from http://www.publicintegrity.org/2014/12/04/16320/benzene-and-worker-cancers-american-tragedy
[409] U.S. Department of Labor, Occupational Safety and Health Administration. (2014). Hydraulic fracturing and flowback hazards other than respirable silica. OSHA 3763-12 2014.

levels in the community environment, the Wisconsin study will appear next year in the *National Journal of Environmental Health*.[410]

- November 11, 2014 – A high-pressure water line ruptured, killing one worker and seriously injuring two others during the hydraulic fracturing of an oil well in Weld County, Colorado.[411]

- October 6, 2014 – Toxicologist Peter Thorne, chair of University of Iowa's Department of Occupational and Environmental Health, warned the Winneshiek County Board of Supervisors about potential community impacts and cancer risks of silica exposure from sand used for fracking operations. Thorne's ongoing investigation, which involves air sampling, risk assessments, and inhalation toxicology studies, focuses on the public health hazards of mining, processing, and storing sand. His team has documented spikes in silica particulate matter related to the transport of the silica sand by rail. The study aims to determine if mining poses an "unacceptable exposure" to the public and quantify the level of risk. For silica-exposed workers, NIOSH continues to identify needed heath protections. Thorne noted, "Workers handling materials should be using respirators, but most are not."[412]

- September 25, 2014 – The Civil Society Institute's Boston Action Research, in cooperation with Environmental Working Group and Midwest Environmental Advocates, issued a report on the hazards of silica mining. The report noted that frac sand mining is expanding rapidly in the United States and poses a little-understood threat to public health, the environment, and local economies. Given the pace of the drilling and fracking boom, silica extraction could spread to a dozen other states with untapped or largely untapped sand deposits, including Illinois, Maine, Massachusetts, Michigan, Missouri, New York, North Carolina, South Carolina, Pennsylvania, Tennessee, Vermont, and Virginia. The *International Business Times* published a summary of the findings.[413, 414]

- August 29, 2014 – In a peer-reviewed study, NIOSH partnered with oil and gas operators and service companies to evaluate worker exposures to, and internal uptake of, volatile organic chemicals at six sites in Colorado and Wyoming where wells were being

[410] Kremer, R. (2014, November 11). High levels of super-fine dust are detected around Wisconsin frac sand mines. *Wisconsin Public Radio*. Retrieved from http://www.wpr.org/high-levels-super-fine-dust-are-detected-around-wisconsin-frac-sand-mines?utm_content=buffer8947f&utm_medium=social&utm_source=facebook.com&utm_campaign=buffer

[411] Paul, J. (2014, November 11). Brighton man ID'd as victim in fatal Weld County fracking blast. *The Denver Post.* Retrieved from http://www.denverpost.com/news/ci_26937782/brighton-man-idd-victim-fatal-weld-county-fracking?source=pkg

[412] Strandberg, S. (2014, October 6). U of I researcher informs supervisors about frac-sand impact. *Decorah Newspapers*. Retrieved from http://www.decorahnewspapers.com/Content/Home/Home/Article/U-of-I-researcher-informs-supervisors-about-frac-sand-impact/-2/-2/35735

[413] Chapman, E., Hopkins, L., Jasset, A., Sheldon, S., & Smith, G. (2014, September 25). Communities at risk: Frac sand mining in the Upper Midwest–A report by Boston Action Research (a project of Civil Society Institute). Retrieved from http://216.30.191.148/fracsandmining/ and www.bit.ly/fracsandmining

[414] Gallucci, M. (2014, September 25). US oil & gas fracking boom could drive silica sand mining operations in 12 more states, environmental groups say. *International Business Times.* Retrieved from http://www.ibtimes.com/us-oil-gas-fracking-boom-could-drive-silica-sand-mining-operations-12-more-states-1695246

prepared for production. The study found benzene in the urine of well pad workers. Benzene is "naturally present in flowback fluids and the time spent working around flowback and production tanks … appears to be the primary risk factor for inhalation exposures." In some cases, airborne concentrations of benzene exceeded the NIOSH Recommended Exposure Limit concentrations and, in a few instances, the American Conference of Governmental Industrial Hygienists' Threshold Limit Value, "when workers performed work tasks near a point source for benzene emissions."[415]

- July 29, 2014 – As part of an investigation into the health impacts of drilling and fracking on animal health, veterinarian Michelle Bamberger and Cornell biochemist Robert Oswald, published an interview with a twenty-year oil and gas industry worker about his experiences and worker safety. His account included injuries, 16-hour workdays, fatigue, exposure to chemicals, and inadequate health and safety training. "No one out there tells you about stuff that has latency. That is the last thing they are going to do is tell you that something that you are handling will take you out in 20 years or 10 years or cause you some kind of ailment, or you can potentially drag this home to your family."[416]

- July 14, 2014 – As part of an analysis of safety and research needs associated with drilling and fracking, researchers at the Colorado School of Public Health and the College of Health Sciences at the University of Wyoming documented high injury and on-the-job mortality rates among gas and oilfield workers. The occupational fatality rate was 2.5 times higher than that of the construction industry and seven times higher than that of general industry. By contrast, injury rates were lower than the construction industry, suggesting that injuries are underreported. Researchers documented crystalline silica levels above occupational health standards and identified the existence of other hazards, including particulate matter, benzene, noise, and radiation. The team called for exposure assessments for both chemical hazards and physical hazards that lead to occupational illness (noise, radioactivity); screening and surveillance systems to assess incidence and prevalence of occupational illness; industry/academic collaboration to conduct occupational epidemiologic studies; and assessment of the effectiveness of industry interventions to reduce exposures.[417]

- July 2014 – The British labor journal *Hazards* identified health concerns in the drilling and fracking industry: increased rate of death on the job, toxic releases, silica exposure, and exposure to hydrocarbons and endocrine disruptors. The union that organizes the construction, rig, and transport workers, on which fracking would rely, agreed at its July 2014 national conference to lobby for a moratorium on fracking because "[d]elegates want union members to be made aware of the dangers of fracking and be advised not to

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415 Esswein, E., Snawder, J., King, B., Breitenstein, M., Alexander-Scott, M., & Kiefer, M. (2014). Evaluation of some potential chemical risks during flowback operations in unconventional oil and gas extraction: Preliminary results. *Journal of Occupational and Environmental Hygiene, 11*, D174-0184.
416 Bamberger, M., & Oswald, R. (2014). The shale gas revolution from the viewpoint of a former industry insider. *NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy.* Early Online View. doi: 10.2190/NS.EOV.1
417 Witter, R. Z., Tenney, L., Clark, S., & Newman, L. S. (2014). Occupational exposures in the oil and gas extraction industry: State of the science and research recommendations. *American Journal of Industrial Medicine, 57*(7), 847-856. Retrieved from http://onlinelibrary.wiley.com/doi/10.1002/ajim.22316/full

work on fracking sites."[418]

- June 29, 2014, and August 31, 2014 – An initial report and follow-up analysis in *The Columbus Dispatch* examined fire hazards at well pads. In one notable case, malfunctioning hydraulic tubing allowed a well pad fire in Monroe County, Ohio to spread rapidly, prompting evacuations. Local firefighters had neither the correct equipment nor did they know the chemicals they were trying to extinguish. One firefighter was treated for smoke inhalation.[419, 420]

- May 19, 2014 – Underscoring the dangerous nature of chemicals used in fracking operations, NIOSH reported that at least four gasfield workers have died since 2010 from acute chemical exposures during flowback operations and warned that flowback operations can "result in elevated concentrations of volatile hydrocarbons in the work environment that could be acute exposure hazards." The agency further noted that such volatile hydrocarbons "can affect the eyes, breathing, and the nervous system and at high concentrations may also affect the heart causing abnormal rhythms."[421, 422]

- May 16, 2013 – A NIOSH study revealed that worker exposure to crystalline silica dust from sand used in fracking operations exceeded "relevant occupational health criteria" at all eleven tested sites, and the magnitude of some exposures exceeded NIOSH limits by a factor of 10 or more. "[P]ersonal respiratory protection alone is not sufficient to adequately protect against workplace exposures." Inhalation of crystalline silica can cause incurable silicosis, lung cancer, chronic obstructive pulmonary disease, kidney disease and autoimmune diseases.[423] Although community exposures distant from mines are possible, there are no federal or state standards for silica in ambient air.[424]

- May 8, 2014 – A report by the AFL-CIO found that the fracking boom has made North Dakota the most dangerous state for U.S. workers—with a fatality rate five times higher than the national average—and that North Dakota's fatality rate has doubled since 2007. The AFL-CIO called North Dakota "an exceptionally dangerous and deadly place to

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[418] O'Neill, R. (editor). (July 2014). Chemicals, dust and deaths and the new rush for oil and gas. *Hazards Magazine*. Special Online Report. Retrieved from http://www.hazards.org/oil/fracking.htm#top

[419] Richards, J. S. (2014, June 29). Glitch sparks smoky fire at gas well. *Columbus Dispatch.* Retrieved from http://www.dispatch.com/content/stories/local/2014/06/29/glitchsparks-smoky-fire-at-gas-well.html

[420] Arenschield, L. (2014, August 31). Fracking fire points out failings. *Columbus Dispatch* Retrieved from http://www.dispatch.com/content/stories/local/2014/06/29/glitchsparks-smoky-fire-at-gas-well.html

[421] Snawder, J., Esswein, E., King, B., Breitenstein, M., Alexander-Scott, M., Retzer, K., . . . Hill, R. (2014, May 19). Reports of worker fatalities during flowback operations [Web log post]. *NIOSH Science Blog.* Retrieved from http://blogs.cdc.gov/niosh-science-blog/2014/05/19/flowback/

[422] Iafolla, R. (2014, May 20). Four fatalities linked to used fracking fluid exposure during 'flowback,' NIOSH reports. *Bloomberg BNA*. Retrieved from http://www.bna.com/four-fatalities-linked-n17179890610/

[423] Esswein, E. J., Breitenstein, M., Snawder, J., Kiefer, M., & Sieber, W. K. (2013). Occupational exposures to respirable crystalline silica during hydraulic fracturing. *Journal of Occupational and Environmental Hygiene, 10*(7), 347-356. doi: 10.1080/15459624.2013.788352

[424] University of Iowa Environmental Health Sciences Research Center. (2012). Exposure assessment and outreach to engage the public on health risks from frac sand mining. Retrieved from http://cph.uiowa.edu/ehsrc/fracsand.html

work." U.S. Secretary of Labor Thomas E. Perez called the rising rate of workplace deaths suffered in the oil and gas sector "unacceptable."[425]

- April 24, 2014 – A University of Texas San Antonio report commissioned by the Methodist Healthcare Ministries found that many oil and gas field workers in the Eagle Ford Shale are uninsured or underinsured and that "the most noticeable health impacts so far are work-related illnesses and injuries: heat exhaustion, dehydration, sleep deprivation, exposure to oil and gas spills and accidents." The study also noted that oil and gas production has put strain on healthcare facilities.[426]

- April 10, 2014 –West Virginia University researcher Michael McCawley reported that some of the nation's highest rates of silicosis are in heavily drilled areas within the Northern Panhandle of West Virginia and southwestern Pennsylvania. A disease that hardens the lungs through inflammation and development of scar tissue, silicosis is entirely attributable to exposure to silica dust, a known occupational hazard at drilling and fracking operations. Two years earlier, OSHA and NIOSH issued a joint "Hazard Alert" to warn fracking workers of the health hazards of exposure to silica dust, including silicosis.[427]

- February 25, 2014 – A year-long investigation by the *Houston Chronicle* found that fracking jobs are deadly, with high fatality rates and high rates of serious injury. Within just one year in Texas, 65 oil and gas workers died, 79 lost limbs, 82 were crushed, 92 suffered burns and 675 broke bones. From 2007 to 2012, at least 664 U.S. workers were killed in oil and gas fields.[428, 429]

- December 27, 2013 – National Public Radio (NPR) reported spiking rates of fatalities related to oil and gas drilling operations, which had increased more than 100 percent since 2009. NPR noted that in the previous year, 138 workers were killed on the job, making the fatality rate among oil and gas workers nearly eight times higher than the average rate of 3.2 deaths for every 100,000 workers across all industries.[430]

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[425] Picchi, A. (2014, May 8). The most dangerous U.S. state for workers. *CBS News*. Retrieved from http://www.cbsnews.com/news/the-most-dangerous-us-state-for-workers/
[426] Ghahremani, Y. (2014, April 24). Fractured Healthcare: Pumping Resources Back into the Eagle For Shale Communities/Executive Summary: Methodist Healthcare Ministries and Center for Community and Business Research at the University of Texas San Antonio. Retrieved from http://www.joomag.com/en/newsstand/fractured-healthcare-pumping-resources-back-into-the-eagle-ford-shale-communities-apr-2014/0368470001398347080
[427] Hicks, I. (2014, April 10). Gas workers risk silica exposure. *The Intelligencer, Wheeling News-Register*. Retrieved from http://www.news-register.net/page/content.detail/id/598589/Gas-Workers-at-Risk-Of-Silica-Ex---.html
[428] Olsen, L. (2014, February 22). Houston Chronicle exclusive: Drilling boom, deadly legacy. Retrieved from http://www.houstonchronicle.com/news/special-reports/article/Houston-Chronicle-exclusive-Drilling-boom-5259311.php#/0
[429] Hsieh, S. (2014, February 25). Why are so many workers dying in oil fields? Retrieved from http://www.thenation.com/blog/178523/why-are-so-many-workers-dying-oil-fields
[430] Schneider, A., & Geewax, M. (2013, December 27). On-the-job deaths spiking as oil drilling quickly expands. Retrieved from http://www.npr.org/2013/12/27/250807226/on-the-job-deaths-spiking-as-oil-drilling-quickly-expands

- October 30, 2012 – In a policy statement, the American Public Health Association (APHA) asserted that, high volume horizontal hydraulic fracturing (HVHF) "poses potential risks to public health and the environment, including groundwater and surface water contamination, climate change, air pollution, and worker health." The statement also noted that the public health perspective has been inadequately represented in policy processes related to HVHF.[431] The policy statement added:

  > [H]ydraulic fracturing workers are potentially exposed to inhalation health hazards from dust containing silica. There may also be impacts on workers and communities affected by the vastly increased production and transport of sand for HVHF. Inhalation of fine dusts of respirable crystalline silica can cause silicosis. Crystalline silica has also been determined to be an occupational lung carcinogen.

- 2005 – A researcher at Stanford University examined hazards associated with oil and gas extraction from exposure to radiation and determined that inhalation of high levels of radon gas is a serious concern to workers and those living nearby. Because the boiling point of radon lies between those of propane and ethane, gaseous radon (222Rn) will concentrate in ethane and propane fractions. "Elevated Rn activity concentration values have been measured at several processing plant sites…. It is well known that the radiological impact of the oil and gas-extracting and processing industry is not negligible."[432]

- May 9, 2003 – A New York Medical College study re-evaluated the chest X-rays of patients with exposure to silica who died from various respiratory problems and found that more than eight percent had undiagnosed silicosis. The study suggested that occupational lung disease may be undercounted in high-risk occupations. The authors of this study said that improved OSHA standards, with ongoing exposure monitoring and medical surveillance, would significantly improve the recognition of cases and justify more stringent preventive measures to reduce exposure. They further noted that practitioners need skills in taking an occupational exposure history. Although ten years have passed since this study was published, both recommendations have yet to be implemented.[433]

Public health effects, measured directly

By several measures, evidence for fracking-related health problems is emerging across the United States and Canada. Studies of birth outcomes in regions of intensive unconventional oil and gas extraction continue to point to reproductive risks, including low birth weight and

[431] American Public Health Association. (2012, October 30). The environmental and occupational health impacts of high-volume hydraulic fracturing of unconventional gas reserves. Retrieved from http://www.apha.org/advocacy/policy/policysearch/default.htm?id=1439

[432] Steinhäusler, F. (2005). Radiological impact on man and the environment from the oil and gas industry: Risk assessment for the critical group. *Nato Science Series: IV: Earth and Environmental Sciences.* doi: 10.1007/1-4020-2378-2_19. http://rd.springer.com/chapter/10.1007/1-4020-2378-2_19

[433] Goodwin, S. S., Stanbury, M., Wang, M.-L., Silbergeld, E., & Parker, J. E. (2003). Previously undetected silicosis in New Jersey decedents. *American Journal of Industrial Medicine, 44,* 304-11. doi: 10.1002/ajim.10260

preterm births. In Pennsylvania, as the number of gas wells increase in a community, so do rates of hospitalization, and community members experience sleep disturbance, headache, throat irritation, stress/anxiety, cough, shortness of breath, sinus, fatigue, wheezing, and nausea. Drilling and fracking operations are also correlated with increased rates of asthma, elevated motor vehicle fatalities, ambulance runs and emergency room visits, and gonorrhea incidence. Benzene levels in ambient air surrounding drilling and fracking operations are sufficient to elevate risks for future cancers in both workers and nearby residents, according to studies. Animal studies show numerous threats to fertility and reproductive success from exposure to various concentrations of oil and gas chemicals, including at levels representative of those found in drinking water. Two dozen chemicals commonly used in fracking operations are endocrine disruptors that can variously disrupt organ systems, lower sperm counts, and cause reproductive harm at levels to which people can be realistically exposed.

- December 13, 2017 – A team of health economists analyzed fracking's health impacts on infants. They examined birth certificates for all 1.1 million infants born in Pennsylvania between 2004 and 2013 and combined these data with maps showing when and where gas wells were drilled in the state. Their results indicated that the introduction of fracking "reduces health among infants born to mothers living within 3 km (1.9 miles) of a well site during pregnancy." For mothers living within one kilometer (.6 miles), they found a 25 percent increase in the probability of low birth weight, "significant declines" in average birth weight, as well as declines in other measures of infant health. They also observed reductions in infant health when mothers lived within one to three kilometers of a fracking site; these were about one-third to one-half of the declines of those mothers living closer.[434] The researchers estimated that "about 29,000 out of the nearly 4 million U.S. births (0.7 percent) annually occur within 1 kilometer of a fracking site and 95,500 are born within 3 kilometers." "For policymakers weighing the costs and benefits of fracking before deciding whether to allow it in their communities, this study provides a clear cost: an increase in the probability of poorer health for babies born near these sites." [435]

- November 6, 2017 – As part of a pilot project, a team of Montreal-based public health researchers evaluated exposure of pregnant mothers to volatile organic compounds (VOCs) in an area of intensive fracking in northeastern British Columbia. At least 28,000 unconventional natural gas wells had been drilled to date in the Peace River Valley. Analyzing the urine of 29 pregnant women, researchers found high concentrations of muconic acid, which is a degradation product of benzene, a widely studied developmental toxicant and an air contaminant in the vicinity of gas wells. The median concentration of this chemical was approximately 3.5 times higher in the study group than in the general Canadian population. In five of the 29 women, the concentration of muconic acid exceeded an exposure index by the American Conference of Governmental Industrial Hygienists that was designed for workplace settings. (No guidelines for the public exist.)

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[434] Currie, J., Greenstone, M., & Meckel, K. (2017). Hydraulic fracturing and infant health: New evidence from Pennsylvania. *Science Advances, 3*(12), e1603021. doi: 10.1126/sciadv.1603021
[435] Currie, J., Greenstone, M., & Meckel, K. (2017). Hydraulic fracturing and infant health: New evidence from Pennsylvania (Research Summary). *Energy Policy Institute at the University of Chicago.* Retrieved from https://epic.uchicago.edu/sites/default/files/EPIC_121017_FrackingResearchSummary_Final.121317.pdf

By design, this small pilot study sets the groundwork for more extensive biomonitoring and environmental analysis.[436]

- September 19, 2017 – University of Texas Health Science Center researchers conducted a case-control study nested within their larger cohort of women with single births (see below) in the 24-county Barnett Shale between November 30, 2010 and November 29, 2012. Its specific purpose was to consider timing of unconventional gas development activity "during potentially sensitive windows of exposure," as well as "potential differences in risk by UGD drilling phase," with regard to preterm births. Results suggest a link between maternal residential proximity to UGD-activity and preterm births, which were similar by drilling phase and "slightly stronger in the first two trimesters of pregnancy."[437]

- September 14, 2017 – Researchers reviewed health assessments taken between February 2012 and October 2015 of adults in Pennsylvania communities with intense unconventional natural gas development (UNGD). The most frequently reported symptoms were sleep disturbance, headache, throat irritation, stress/anxiety, cough, shortness of breath, sinus problems, fatigue, wheezing, nausea, each occurring in over 20 percent of the sample. Over 43 percent of the sample reported sleep disturbance. To meet the inclusion criteria, as developed and implemented by a physician and nurse practitioner, the symptoms were reviewed to ensure no plausible cause relating to "past medical and surgical history, concurrent medical conditions, family and social history, and environmental exposures unrelated to UNGD. For example, if the social history indicated a ½ pack/day smoking history, the symptom of 'difficulty breathing' was not included." Independently, the timing of the exposure for each symptom that met the inclusion criteria was determined, using the beginning drilling date for each unconventional natural gas well within one kilometer (.6 miles) of the patient's residence; records were excluded if it was not possible to verify at least one gas well within this distance.[438]

- August 21, 2017 – Using county-level data from 2003 to 2013, researchers found that, all together, counties in the Marcellus Shale region that experienced a boom in hydraulic fracturing showed a 20 percent increase in the incidence rate of gonorrhea.[439]

- July 21, 2017 – A University of Texas Health Science Center School of Public Health team assessed the links between the residential proximity of pregnant mothers to

[436] Caron-Beaudoina, É, Valter, N., Chevrier, J., Ayotte, P., Frohlich, K., & Verner, M.-A. (2017). Gestational exposure to volatile organic compounds (VOCs) in Northeastern British Columbia, Canada: A pilot study. *Environment International, 110,* 131-138. doi: 10.1016/j.envint.2017.10.022

[437] Marshall, A. K., Symanski, E., & Whitworth, K. W. (2017). The association between unconventional gas development and preterm birth: Evaluating drilling phases and critical windows of susceptibility [Abstract]. *Annals of Epidemiology, 27*(8), 530.

[438] Weinberger, B., Greiner, L. H., Walleigh, L., & Brown, D. (2017). Health symptoms in residents living near shale gas activity: A retrospective record review from the Environmental Health Project. *Preventive Medicine Reports, 8,* 112-115. doi: 10.1016/j.pmedr.2017.09.002

[439] Komarek, T., & Cseh, A. (2017). Fracking and public health: Evidence from gonorrhea incidence in the Marcellus Shale region. *Journal of Public Health Policy, 38*(4), 464-481. doi: 10.1057/s41271-017-0089-5

unconventional natural gas development activity and various newborn health problems: preterm birth, small-for-gestational age (SGA), fetal death, and low birth weight. They found evidence of a "moderate positive association" between residential proximity to UGD-activity and increased odds of preterm birth, and a "suggestive association" with fetal death. Nearly 159,000 births and fetal deaths from November 30, 2010 to November 29, 2012 in the 24-county Barnett Shale area were considered.[440]

- February 15, 2017 – A study from the University of Colorado School of Public Health and Anschutz Medical Campus showed that children and young adults between the ages of 5 and 24 with acute lymphocytic leukemia (ALL) were 4.3 times more likely to live in area dense with active oil and gas wells. The researchers did not find such a link with ALL cases in 0-4 year olds, or with incidence of non-Hodgkin lymphoma. The study focused on rural areas and towns in 57 Colorado counties and did not include cities of more than 50,000 people. Authors wrote, "Because oil and gas development has potential to expose a large population to known hematologic carcinogens, such as benzene, further study is clearly needed to substantiate both our positive and negative findings."[441]

- August 25, 2016 – Researchers found that Pennsylvanians residing near intensive unconventional gas well activity were significantly more likely to experience chronic rhino sinusitis (at least three months of nasal and sinus symptoms), migraine headaches, and higher levels of fatigue than residents who do not live near such activity.[442] Data were gathered from nearly 8,000 patients of Geisinger Health System from 40 counties in north and central Pennsylvania, and matched with the proximity of respondents to all phases of gas drilling activity and intensity, using information from the Pennsylvania Departments of Environmental Protection (PA DEP) and Conservation and Natural Resources, as well as satellite imagery. According to lead author Aaron W. Tustin, MD, MPH, resident physician in the Department of Environmental Health Sciences at the Johns Hopkins Bloomberg School of Public Health, "[t]hese three health conditions can have debilitating impacts on people's lives… In addition, they cost the health care system a lot of money."[443]

- July 18, 2016 – Living near fracking operations significantly increases asthma attacks, according to a Johns Hopkins University study of 35,000 medical records of people with

[440] Whitworth, K. W., Marshall, A. K., & Symanski, E. (2017). Maternal residential proximity to unconventional gas development and perinatal outcomes among a diverse urban population in Texas. *PLOS ONE, 12*(7), e0180966. doi: 10.1371/journal.pone.0180966
[441] McKenzie, L. M., Allshouse, W. B., Byers, T. E., Bedrick, E. J., Serdar, B., & Adgate, J. L. (2017). Childhood hematologic cancer and residential proximity to oil and gas development. *PLOS ONE, 12*(2), e0170423. doi: 10.1371/journal.pone.0170423
[442] Tustin, A. W., Hirsch, A. G., Rasmussen, S. G., Casey, J. A., Bandeen-Roche, K., & Schwartz, B. S. (2017). Associations between unconventional natural gas development and nasal and sinus, migraine headache, and fatigue symptoms in Pennsylvania. *Environmental Health Perspectives*, *125,* 189-197. doi: 10.1289/EHP281
[443] Phillips, S. (25 August, 2016). New study links gas drilling to migraines, fatigue and chronic sinus symptoms. *State Impact Pennsylvania.* Retrieved from https://stateimpact.npr.org/pennsylvania/2016/08/25/new-study-points-to-association-between-gas-drilling-to-migraines-fatigue-and-chronic-sinus-symptoms/

asthma in north and central Pennsylvania, from 2005 to 2012.[444] The data show that those who live near a higher number of, or larger, active gas wells were 1.5 to 4 times more likely to suffer from asthma attacks compared to those who live farther away, with the closest group having the highest risk. There was increased risk in all three types of exacerbations defined: mild (new oral corticosteroid medication order), moderate (emergency department encounter), or severe (hospitalization). In addition, researchers identified increased risk during all four phases of well development: pad preparation, drilling, stimulation (fracking), and production. The study was praised for its “rigorous research methods,” by a scientist not part of the team.[445]

- July 5, 2016 – Researchers from five universities and the U.S. Geological Survey (USGS) identified a link between exposure to fracking and drilling chemicals and adverse reproductive and developmental outcomes in laboratory mice. The study used 23 oil and gas chemicals in four different concentrations, representing concentrations found in drinking water and groundwater, to higher concentrations found in oil and gas industry wastewater. Offspring of pregnant laboratory mice consuming these mixtures were compared to those that did not. Results suggested “numerous potential threats to fertility and reproductive success … including altered pituitary hormone levels, reproductive organ weights, and disrupted ovarian follicle development.” Researchers observed these negative outcomes even in the offspring exposed to the lowest dose of chemicals. Building on previous research showing reduced sperm counts in male offspring, they also reported on “tentative mechanistic information for the observed adverse health effects.”[446]

- February 9, 2016 – An exploratory study of hospitalization rates for three study areas in Queensland, Australia showed rates for specific types of hospital admissions increased more quickly in a coal seam gas study area than in other study areas (a coal mining area and a rural/agricultural area). Coal seam gas is the methane trapped in pores and fractures in underground coal deposits; its exploitation is a form of unconventional natural gas development. A portion of coal seam gas extraction uses fracking. This preliminary study found the strongest link between increased hospitalization rates over time in a coal seam gas area to be for the category of ‘Blood/immune’ diseases.[447]

- October 14, 2015 – Using an animal model, an interdisciplinary research team measured the endocrine-disrupting activities of 24 chemicals used and/or produced by oil and gas

[444] Rasmussen, S. G., Ogburn, E. L., McCormack, M., Casey, J. A., Bandeen-Roche, K. Mercer, D. G., & Schwartz, B. S. (2016). Association between unconventional natural gas development in the Marcellus Shale and asthma exacerbations. *JAMA Internal Medicine.* Advance online publication. doi: 10.1001/jamainternmed.2016.2436
[445] Song, L., & Kusnetz, N. (2016, July 18). Increased asthma attacks tied to exposure to natural gas production. *InsideClimate News.* Retrieved from https://insideclimatenews.org/news/18072016/asthma-study-marcellus-shale-pennsylvania-natural-gas-fracking
[446] Kassotis, C. D., Bromfield, J. J., Klemp, K. C., Meng, C-X., Wolfe, A., Zoeller, R. T., . . . Nagel, S. C. (2016). Adverse reproductive and developmental health outcomes following prenatal exposure to a hydraulic fracturing chemical mixture in female C57Bl/6 Mice. *Endocrinology, 157*(9), 3469–3481. doi: 10.1210/en.2016-1242
[447] Werner, A. K., Watt, K., Cameron, C. M., Vink, S., Page, A., & Jagals, P. (2016). All-age hospitalization rates in coal seam gas areas in Queensland, Australia, 1995–2011. *BMC Public Health, 16* (125). doi: 10.1186/s12889-016-2787-5

operations, finding that 23 of them "can activate or inhibit the estrogen, androgen, glucocorticoid, progesterone, and/or thyroid receptors, and mixtures of these chemicals can behave synergistically, additively, or antagonistically." Further, the researchers tested prenatal exposures to the chemicals and found effects on multiple organs, including adverse reproductive effects on the matured offspring.[448] This study is the first to demonstrate that endocrine-disrupting chemicals, which are commonly used in fracking operations, can harm the reproductive health of mice, at levels of exposure that are realistic for humans. The study's senior author told *ScienceDaily,* "In addition to reduced sperm counts, the male mice exposed to the mixture of chemicals had elevated levels of testosterone in their blood and larger testicles. These findings may have implications for the fertility of men living in regions with dense oil and/or natural gas production."[449]

- October 8, 2015 – Pregnant women who live near active fracking operations in Pennsylvania were at a 40 percent increased risk of giving birth prematurely and at a 30 percent increased risk for having obstetrician-labeled high-risk pregnancies, according to a study by Johns Hopkins Bloomberg School of Public Health and other researchers. High-risk pregnancies were those that included hypertension, high pre-pregnancy body mass index, and asthma. The study used data from the Geisinger Health System on 9,384 pregnant women and their 10,496 newborns between January 2009 and January 2013; Geisinger covers 40 counties in north and central Pennsylvania. Researchers developed an index for proximity to fracking wells based on distance from the women's homes, stage of drilling and depth of wells dug, and the amount of gas that was produced at those wells during the pregnancies. The highest-activity quartile had the highest rates of premature births and high-risk pregnancies.[450, 451]

- July 22, 2015 – Using a mammal model, New York University School of Medicine scientists, together with other U.S. and Chinese researchers, demonstrated cancerous changes linked to exposure to wastewater from Marcellus fracking operations. Their study also documented elevated levels of barium and strontium in exposed animal cells. The wastewater studied originated in Pennsylvania and was stored for a time to allow radioactivity and levels of short-lived VOCs to decline. The results suggest that "even aged flow back water could pose substantial health threats to exposed humans."[452]

- July 15, 2015 – A study by University of Pennsylvania and Columbia University

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[448] Kassotis, C.D., Klemp, K.C., Vu, D.C., Lin, C.-H., Meng, C.-X., Besch-Williford, C.L., . . . Nagel, S.C. (2015). Endocrine-disrupting activity of hydraulic fracturing chemicals and adverse health outcomes after prenatal exposure in male mice. *Endocrinology 156*(12), 4458–4473. doi: 10.1210/en.2015-1375
[449] Endocrine Society. (2015, October 14). Fracking chemicals tied to reduced sperm count in mice. *ScienceDaily.* Retrieved from www.sciencedaily.com/releases/2015/10/151014134533.htm
[450] Casey, J. A., Savitz, D. A., Rasmussen, S. G., Ogburn, E. L., Pollak, J., Mercer, D. G., & Schwartz, B. S. (2016). Unconventional natural gas development and birth outcomes in Pennsylvania, USA. *Epidemiology 27*(2), 163–172. doi: 10.1097/EDE.0000000000000387
[451] Johns Hopkins Bloomberg School of Public Health. (2015, October 8). Study: fracking industry wells associated with premature birth. Retrieved from http://www.jhsph.edu/news/news-releases/2015/study-fracking-industry-wells-associated-with-premature-birth.html
[452] Yao, Y., Chen, T., Shen, S. S., Niu, Y., DesMarais, T. L., Linn, R., . . . Costa, M. (2015). Malignant human cell transformation of Marcellus Shale gas drilling flow back water. *Toxicology and Applied Pharmacology, 288,* 121-130. doi: 10.1016/j.taap.2015.07.011

researchers found that drilling and fracking activity was associated with increased rates of hospitalization in Pennsylvania. During a period of dramatic increase in drilling and fracking activity between 2007 and 2011, inpatient prevalence rates surged for people living near shale gas wells. Cardiology inpatient prevalence rates were significantly associated with number of wells per zip code and their density, while neurology inpatient prevalence rates were significantly associated with density of wells. Hospitalizations for cancer, skin conditions, and urological problems also rose significantly. During the same time period, no such increase in health problems was observed in a control Pennsylvania county without any drilling and fracking activity. In communities with the most wells, the rate of cardiology hospitalizations was 27 percent higher than in control communities with no fracking. "While the clinical significance of the association remains to be shown, [fracking] has just begun in Pennsylvania, and thus observing a significant association over this short time is striking.… Our study also supports the concept that health care utilization should be factored into the value (costs and benefits) of hydraulic fracturing over time."[453] In a related *Newsweek* story, lead researcher Reynold Panettieri, Jr. said, "At this point, we suspect that residents are exposed to many toxicants, noise and social stressors due to hydraulic fracturing near their homes and this may add to the increased number of hospitalizations."[454]

- July 9, 2015 – As part of a scientific assessment of well stimulation treatments, including fracking, the California Council on Science and Technology studied the potential impacts of well stimulation on human health in California. The risk factors directly attributable to well stimulation stem largely from the use of a very large number and quantity of stimulation chemicals. The unknown number and toxicity of chemicals that are mixed together in well stimulation fluids made it difficult to fully quantify risk to the environment and to human health, but the study highlighted the potential health risks from exposure to fracking-related air pollution for the people of Los Angeles, 1.7 million of whom live or work within one mile of an active oil or gas well.[455] Jane Long, co-author, said, "officials should fully understand the toxicity and environmental profiles of all chemicals before allowing them to be used in California's oil operations," according to the *Los Angeles Times*.[456]

- June 22, 2015 – A longtime midwife reported her personal analysis of an ongoing spike in infant deaths, miscarriages, and placental abnormalities in Utah's Uintah Basin that has

[453] Jemielita T., Gerton G. L., Neidell, M., Chillrud S., Yan B., Stute, M., . . . Panettieri, Jr., R. A. (2015), Unconventional gas and oil drilling is associated with increased hospital utilization rates. *PLoS ONE 10*(7), e0131093. doi: 10.1371/journal.pone.0131093

[454]Schlanger, Z. (2015, July 15). Living near fracking wells linked to increased hospitalization rates. *Newsweek*. Retrieved from http://www.newsweek.com/living-near-fracking-wells-linked-increased-hospitalization-rates-354093

[455] Shonkoff, S. B. C., Maddalena, R. L., Hays, J., Stringfellow, W., Wettstein, Z. S., Harrison, R., Sandelin, W., & McKone, T. E. (2015, July 9). Potential impacts of well stimulation on human health in California, in California Council of Science and Technology and Lawrence Berkeley National Laboratory, *An Independent Scientific Assessment of Well stimulation in California, vol. 2: Potential Environmental Impacts of Hydraulic Fracturing and Acid Stimulations*. Retrieved from http://ccst.us/publications/2015/2015SB4-v2.pdf

[456] Cart, J. (2015, July 9). Water and wildlife may be at risk from fracking's toxic chemicals, panel finds. *Los Angeles Times.* Retrieved from http://www.latimes.com/local/lanow/la-me-california-science-panel-warns-that-fracking-poses-unknown-risk-20150709-story.html

followed the advent of drilling and fracking activity there and appears linked to air pollution episodes.[457]

- June 3, 2015 – A University of Pittsburgh study linked fracking to low birthweight in three heavily drilled Pennsylvania counties. The more exposure a pregnant woman had to gas wells, the higher her risk for a smaller-than-normal baby. Exposure was determined as proximity and density of wells in relation to the residence of the pregnant woman. Compared to mothers whose homes had the fewest surrounding gas wells, mothers whose homes were nearest to a high density of wells were 34 percent more likely to have babies who were "small for gestational age," meaning they weighed significantly less than expected for the number of weeks of pregnancy. Although the study did not investigate mechanisms, researchers identified air as the likely route of exposure. They supported this argument by referencing another study done in Western Pennsylvania where airborne particulate pollution correlated with low birth weight and by noting that particulates are established shale gas infrastructure emissions.[458, 459] Low birth weight is a leading cause of infant mortality.

- March 3, 2015 – A follow-up study of 21 case studies from five states found that the distribution of symptoms in animals and humans affected by nearby fracking operations was, since 2012, unchanged for humans and companion animals. In food animals, reproductive problems decreased over time while respiratory problems and growth problems increased. "This longitudinal case study illustrates the importance of obtaining detailed epidemiological data on the long-term health effects of multiple chemical exposures and multiple routes of exposure that are characteristic of the environmental impacts of unconventional drilling operations."[460]

- March 3, 2015 – A cross-sectional study by Yale University School of Medicine researchers using companion animals as sentinels of human exposure to fracking-related chemicals investigated possible associations between reported health conditions of companion and backyard animals in Southwest Pennsylvania and household proximity to drilling and fracking operations. Among dogs living in households located less than one kilometer from a gas well, risks for health problems were elevated, especially for dermal conditions, compared to animals living more than two kilometers from a well.[461]

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457 Solotaroff, P. (2015, June 22). What's killing the babies of Vernal, Utah? *Rolling Stone*. Retrieved from http://www.rollingstone.com/culture/features/fracking-whats-killing-the-babies-of-vernal-utah-20150622

458 Shaina, L. S., Brink, L. L, Larkin, J. D., Sadovsky, Y, Goldstein, B. C., Pitt, B. R., & Talbott, E. O. (2015). Perinatal outcomes and unconventional natural gas operations in southwest Pennsylvania. *PLoS One, 10,* e0126425. doi: 10.1371/journal.pone.0126425

459 Preidt, R. (2015, June 3). 'Fracking' linked to low birth weight babies, *WebMD*. Retrieved from http://www.webmd.com/parenting/baby/news/20150603/fracking-linked-to-low-birth-weight-babies

460 Bamberger, M. & Oswald, R. E. (2015). Long-term impacts of unconventional drilling operations on humans and animal health. *Journal of Environmental Science and Health, Part A*: *Toxic/Hazardous Substances and Environmental Engineering, 50,* 447-59. doi: 10.1080/10934529.2015.992655

461 Slizovskiy, I. B., Conti, L. A., Trufan, S. J., Reif, J. S., Lamers, V. T., Stowe, M. H., Dziura, J., & Rabinowitz, P. M. (2015). Reported health conditions in animals residing near natural gas wells in southwestern Pennsylvania, *Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances and Environmental Engineering*, *50*(5), 473-481, doi: 10.1080/10934529.2015.992666

- January 1, 2015 – A Yale-led team studied the relationship between household proximity to drilling and fracking operations and reported health symptoms in Washington County, Pennsylvania where 624 gas wells were in active operation, most of which had been drilled in the past five to six years. Researchers found that health symptoms reported by residents increased in frequency as distance between household and gas wells decreased. Among persons living less than one kilometer from drilling and fracking operations, rashes and upper respiratory problems were more prevalent. The authors of this study, the largest to date on the link between reported symptoms and natural gas drilling activities, say that their findings are "… consistent with earlier reports of respiratory and dermal conditions in persons living near natural gas wells." They also cite literature demonstrating the biological plausibility of a link between oil and gas extraction activities and both categories of health effects reported.[462]

- December 17, 2014 – As part of a lengthy review that became the foundation for New York State's ban on high volume hydraulic fracturing, the New York State Department of Health (NYS DOH) identified environmental problems associated with fracking that could contribute to adverse public health impacts. Among them: air pollution (particulate matter, ozone, diesel exhaust, and VOCs) that could affect respiratory health; drinking water contamination from underground migration of methane and/or fracking chemicals associated with faulty well construction or seismic activity; drinking water contamination from inadequate water treatment of fracking waste or from surface spills of fracking chemicals or wastewater; earthquakes and the creation of fissures; increased vehicle traffic; increased noise; increased demand for housing and medical care; and public health problems related to climate change impacts from methane and other greenhouse gas emissions into the atmosphere. The NYS DOH Public Health Review also discussed findings from surveys of health symptoms among residents living near high volume hydraulic fracturing activities. These included skin rash, nausea or vomiting, abdominal pain, breathing difficulties, cough, nosebleed, anxiety, stress, headache, dizziness, eye irritation, and throat irritation in populations living near drilling and fracking operations. The NYS DOH Public Health Review noted that ongoing studies by both government agencies and several academic institutions were exploring the public health risks and impacts of fracking but that many of these studies were years from completion. The review concludes:

  > … significant gaps exist in the knowledge of potential public health impacts from [high volume hydraulic fracturing]…. The existing science investigating associations between [high volume hydraulic fracturing] activities and observable adverse health outcomes is very sparse and the studies that have been published have significant scientific limitations. Nevertheless, studies are suggestive of potential public health risks related to [high volume hydraulic fracturing] activity that warrant further careful evaluation.

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[462] Rabinowitz, P. M. Slizovskiy, I. B, Lamers, V., Trufan, S. J., Holford, T. R., Dziura, J. D., … Stowe, M. H. (2015). Proximity to natural gas wells and reported health status: results of a household survey in Washington County, Pennsylvania. *Environmental Health Perspectives, 123*, 21-26. doi: 10.1289/ehp.1307732. See also footnote 29.

In an accompanying letter to the New York State Department of Environmental Conservation, Health Commissioner Howard Zucker, MD, concluded,

> … the overall weight of the evidence from the cumulative body of information contained in this Public Health Review demonstrates that there are significant uncertainties about the kinds of adverse health outcomes that may be associated with [high volume hydraulic fracturing], the likelihood of the occurrence of adverse health outcomes and the effectiveness of some of the mitigation measures in reducing or preventing environmental impacts which could adversely affect public health. Until the science provides sufficient information to determine the level of risk to public health from [fracking] to all New Yorkers and whether the risks can be adequately managed, DOH recommends that high volume hydraulic fracturing should not proceed in NYS.[463]

- October 13, 2014 – According to the North Dakota Health Department, the number of HIV and AIDS cases in North Dakota more than doubled between 2012 and 2014, and cases were shifting to the state's western oil fields, where 35-40 percent of all new cases occurred. Previously, only 10 percent of cases were in that region.[464] This trend followed on the heels of an upsurge in sexually transmitted chlamydia cases in the same region. The North Dakota state director of disease control, Kirby Kruger, attributed the uptick in HIV cases to the drilling and fracking industry and attempted to spread HIV prevention messages at the "man camps" that house young male workers in the oil industry.[465] Human trafficking for purposes of prostitution accompanied the fracking boom, but there was a shortage of medical professionals to address this public health crisis, according to Kruger, who noted that it was difficult to hire nurses and medical staff who could live in the area on a public health wage.

- October 2, 2014 – According to researchers from the University of Pennsylvania's Center of Excellence in Environmental Toxicology, an increasing number of gas wells in Pennsylvania is significantly correlated with inpatient rates of hospitalization. The research team collected data from seven different insurance providers for three counties; the study's publication is forthcoming.[466]

- September 11, 2014 – In Texas, commercial vehicle accidents have increased more than 50 percent since 2009 when the state's ongoing drilling and fracking boom began,

[463] New York State Department of Health. (2014, December 17). *A public health review of high volume hydraulic fracturing for shale gas development*. Retrieved from http://www.health.ny.gov/press/reports/docs/high_volume_hydraulic_fracturing.pdf
[464] Associated Press. (2014, October 13). North Dakota HIV/AIDs rate rises with population growth. Retrieved from http://billingsgazette.com/news/state-and-regional/montana/north-dakota-hiv-aids-rate-rises-with-population-growth/article_a939fed6-f737-5cfb-957f-ab800673f4d7.html
[465] Heitz, D. (2014, September 30). Oil boom helps fuel surge in HIV in North Dakota. *HealthlineNews.* Retrieved from http://www.healthline.com/health-news/oil-boom-helps-fuel-hiv-surge-north-dakota-093014#1
[466] Skrapits, E. (2014, October 2). Study: More gas wells in area leads to more hospitalizations. *The Citizen's Voice*. Retrieved from http://citizensvoice.com/news/study-more-gas-wells-in-area-leads-to-more-hospitalizations-1.1763826

according to an investigation by the *Houston Chronicle* and Houston Public Media News 88.7. "For six decades, highway deaths have dropped steadily all across the United States…. But in Texas all motor vehicle fatalities – and accidents involving commercial trucks – have turned back upward since the state's oil drilling and fracking boom began in 2008." This rising motor vehicle death toll is especially felt in formerly rural counties in the Eagle Ford and Permian Basin, now places of heavy drilling and fracking. A new Department of Public Safety "Road Check" program finds annually, "27 to 30 percent of Texas' commercial trucks shouldn't be operating at all due to potentially life-threatening safety problems like defective brakes, bald tires, inoperable safety lights and unqualified, unfit or intoxicated drivers."[467, 468]

- August 3, 2014 – Hospitals in the Bakken Shale region reported a sharp rise in ambulance calls and emergency room visits after 2006. "Mercy Medical Center in Williston and the Tioga Medical Center in neighboring Williams County saw their ambulance runs increase by more than 200 percent. Tioga's hospital saw a staggering leap in trauma patients by 1,125 percent. Mercy had a 373 percent increase." Drugs (including overdoses of prescription drugs, methamphetamine, and heroin) explain many of the cases, with oilfield related injuries such as "fingers crushed or cut off, extremity injuries, burns and pressure burns" accounting for 50 percent of the cases in one of the region's hospital emergency rooms.[469]

- May 21, 2014 – Raising questions about possible links to worsening air pollution from the Uintah Basin's 11,200 oil and gas wells, health professionals reported that infant deaths in Vernal, Utah, rose to six times the normal rate over the past three years. Physician Brian Moench said, "We know that pregnant women who breathe more air pollution have much higher rates of virtually every adverse pregnancy outcome that exists…. And we know that this particular town is the center of an oil and gas boom that's been going on for the past five or six years and has uniquely high particulate matter and high ozone."[470] Although it formerly had pristine air quality, Uintah County, Utah received a grade "F" for ozone in the American Lung Association's 2013 State of the Air Report.[471]

- January 28, 2014 – Congenital heart defects, and possibly neural tube defects in newborns, were associated with the density and proximity of natural gas wells within a 10-mile radius of mothers' residences in a study of almost 25,000 births from 1996 to 2009 in rural Colorado. The researchers note that natural gas development emits several

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[467] Olsen, L. (2014, 11 September). Fatal truck accidents have spiked during Texas' ongoing fracking and drilling boom. *Houston Chronicle.* Retrieved from http://www.houstonchronicle.com/news/article/Fracking-and-hydraulic-drilling-have-brought-a-5747432.php?cmpid=email-premium&cmpid=email-premium&t=1a9ca10d49c3f0c8a9#/0
[468] Schneider, A. (2014, 12 October). In Texas, traffic deaths climb amid fracking boom. *National Public Radio*. Retrieved from http://www.npr.org/2014/10/02/352980756/in-texas-traffic-deaths-climb-amid-fracking-boom
[469] Bryan, K. J. (2014, August 3). Drugs, oilfield work, traffic pushing more people through doors of Watford City ER. *Bakken Today.* Retrieved from http://www.bakkentoday.com/event/article/id/37101/
[470] Schlanger, Z. (2014, May 21). In Utah boom town, a spike in infant deaths raises questions. *Newsweek*. Retrieved from http://www.newsweek.com/2014/05/30/utah-boom-town-spike-infant-deaths-raises-questions-251605.html
[471] American Lung Association. (2013). American Lung Association state of the air 2013. Retrieved from http://www.stateoftheair.org/2013/states/utah/uintah-49047.html

chemicals known to increase risk of birth defects (teratogens).[472]

- January 4, 2014 – Preliminary data from researchers at Princeton University, Columbia University, and MIT showed elevated rates of low birthweight among infants born to mothers living near drilling and fracking operations during their pregnancies.[473]

- October 2013 – A preliminary study of the health impacts of oil and gas extraction on infant health in Colorado found that proximity to wells—linked with air pollutants from fracking operations—was associated with reductions in average birthweight and length of pregnancy as well as increased risk for low birthweight and premature birth.[474] A study by the same author, currently under review, which analyzed births to Pennsylvania mothers residing close to a shale gas well in Pennsylvania from 2003 to 2010, also identified increased risk of adverse effects. This includes low birth weight, as well as a 26 percent increase in APGAR scores under 8. (APGAR—or American Pediatric Gross Assessment Record—is a measure of newborn responsiveness. Scores of less than 8 predict an increase in the need for respiratory support.)[475]

- August 26, 2013 – Medical experts at a rural clinic in heavily-drilled Washington County, Pennsylvania reported case studies of 20 individuals with acute symptoms consistent with exposure to air contaminants known to be emitted from local fracking operations.[476, 477]

- May 2, 2013 – A community-based participatory research study in Pennsylvania tested air and water quality and surveyed self-reported health symptoms of more than 100 residents living near drilling and fracking operations. The team detected a total of 19 volatile organic compounds (VOCs) in ambient air sampled outside of homes. The reported health symptoms closely matched the established effects of chemicals detected through air and water testing at those nearby sites. Moreover, those symptoms occurred at significantly higher rates in households closer to the gas facilities than those farther away.[478] Indicative of the growing prevalence of such health impacts in the state, a poll

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[472] McKenzie, L. M., Guo, R., Witter, R. Z., Savitz, D. A., Newman, L. S., & Adgate, J. L. (2014). Birth outcomes and maternal residential proximity to natural gas development in rural Colorado. *Environmental Health Perspectives, 122*, 412-417. doi: 10.1289/ehp.1306722
[473] Whitehouse, M. (2014, January 4). Study shows fracking is bad for babies. *Bloomberg*. Retrieved from http://www.bloombergview.com/articles/2014-01-04/study-shows-fracking-is-bad-for-babies
[474] Hill, E. L. (2013, October). The impact of oil and gas extraction on infant health in Colorado. Retrieved from http://www.elainelhill.com/research
[475] Hill, E. L. (2013, December). Shale gas development and infant health: Evidence from Pennsylvania (under review). Retrieved from http://www.elainelhill.com/research.
[476] Abrams, L. (2013, August 26). Fracking's real health risk may be from air pollution. *Salon*. Retrieved from http://www.salon.com/2013/08/26/frackings_real_health_risk_may_be_from_air_pollution/
[477] Dyrszka, L., Nolan, K., & Steingraber, S. (2013, August 27). *Statement on preliminary findings from the Southwest Pennsylvania Environmental Health Project study* [Press release]. Concerned Health Professionals of NY. Retrieved from http://concernedhealthny.org/statement-on-preliminary-findings-from-the-southwest-pennsylvania-envir. . .
[478] Steinzor, N., Subra, W., & Sumi, L. (2013). Investigating links between shale gas development and health impacts through a community survey project in Pennsylvania. *NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy, 23*(1), 55-83. doi: 10.2190/NS.23.1.e

showed that two-thirds of Pennsylvanians support a moratorium on fracking because of concern about negative health impacts.[479]

Noise pollution, light pollution, and stress

Drilling and fracking operations and ancillary infrastructure expose workers and nearby residents to continuous noise and light pollution that is sustained for periods lasting many months. Chronic exposure to light at night is linked to adverse health effects, including breast cancer. Sources of fracking-related noise pollution include blasting, drilling, flaring, generators, compressor stations, and truck traffic. Exposure to environmental noise pollution is linked to cardiovascular disease, cognitive impairment, and sleep disturbance. Oil and gas production noise may be disrupting wildlife health in protected areas. Workers and residents whose homes, schools, and workplaces are in close proximity to well sites are at risk from these exposures as well as from related stressors. Existing "setback distances" may not be adequate to reduce public health threats, especially for vulnerable populations. A UK Health Impact Assessment (HIA) identified stress and anxiety resulting from drilling-related noise—as well as from a sense of uncertainty about the future and eroded public trust—as key public health risks related to fracking operations.

- May 5, 2017 – Oil and gas production was one of the main anthropogenic noise sources (though the proportion for which it was responsible was not determined) in a study that quantified the degree and extent of noise pollution in U.S. protected areas (PAs) and critical habitat for endangered species. Authors "compared noise pollution among land management and protection status and investigated sources responsible for generating noise across PAs." The team of biologists and engineers found that human-caused noise doubled background sound in 63 percent of U.S. protected areas, and produced a tenfold or greater increase in 21 percent of protected areas. These levels are "known to interfere with human visitor experience and disrupt wildlife behavior, fitness, and community composition." Researchers also found a 10-fold increase in sound levels in 14 percent of critical habitats of endangered species.[480]

- April 3, 2017 – A University of Maryland team conducted a pilot study of noise pollution at eight homes located less than a half mile (750 meters) from natural gas compressor stations in West Virginia and compared decibel levels to those collected from homes located further away. They found that daytime and nighttime noise levels were higher at properties located closer to a compressor, as measured both inside and outside the homes. Five of six homes that were monitored for a full 24-hour period had combined day-night indoor average noise levels that exceed 60 decibels (dBA), which exceeds both EPA's recommended limits for chronic noise exposure as well those recommended by the World

[479] Phillips, S. (2013, May 14). Poll shows support for a drilling moratorium in Pennsylvania. *StateImpact*. Retrieved from http://stateimpact.npr.org/pennsylvania/2013/05/14/poll-shows-support-for-a-drilling-moratorium-in-pennsylvania/
[480] Buxton, R. T., McKenna, M. F., Mennitt, D., Fristrup, K., Crooks, K., Angeloni, L., & Wittemyer, G. (2017). Noise pollution is pervasive in U.S. protected areas. *Science, 356* (6337), 531-533. doi: 10.1126/science.aah4783

Health Organization. To date, no federal noise standards exist for oil and gas operations. Noting that noise exposure has been associated in previous studies with sleep disruption, poor academic performance, and hypertension, the authors conclude, "Findings indicate that living near natural gas compressor stations could potentially result in high environmental noise exposures. Larger studies are needed to confirm these findings and evaluate potential health impacts and protections measures."[481]

- December 9, 2016 – A review analyzing the relevant scientific literature on the potential public health impacts of ambient noise related to unconventional oil and gas development found that "oil and gas activities produce noise at levels that may increase the risk of adverse health outcomes, including annoyance, sleep disturbance, and cardiovascular disease." The team of environmental and occupational health scientists collected available measurements of noise levels at oil and gas operations and analyzed the data with established noise standards. Authors stated that many noise sources from fracking operations are similar to those of conventional oil and gas development, but that high-volume hydraulic fracturing activities present additional noise risks. These arise from conditions including four to five times the length of time needed to drill the well, and the much greater volume of water and higher pressures needed, compared to a traditional vertical well. They described the complexity of noise associated with oil and gas operations, including both intermittent and continuous noise, varying in intensities. The review included focus on vulnerable populations, including children, the elderly, and the chronically ill. Authors noted that existing "setback distances" – already often the result of political compromise and not evidence-based – may be insufficient to reduce public health threats, and that maximum allowable noise levels should be lower for schools and hospitals.[482]

- July 9, 2015 – As part of its assessment of potential health impacts, the California Council of Science and Technology looked at the impacts of noise and light pollution from oil and gas operations in California. The researchers noted that a number of activities associated with drilling and fracking generated noise at levels considered dangerous to public health. Noise is a biological stressor that can aggravate or contribute to the development of hypertension and heart problems. In California, noise from well stimulation was associated with both sleep disturbance and cardiovascular disease in a dose-response relationship. Exposure to artificial light at night has been linked to breast cancer in women, although almost no research has been conducted on the public health implications of light pollution from oil and gas extraction specifically.[483]

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481 Boyle, M. D., Soneja, S., Quirós-Alcalá, L., Dalemarre, L., Sapkota, A. R., Sangaramoorthy, T. … Sapkota, A. (2017). A pilot study to assess residential noise exposure near natural gas compressor stations. *PLoS ONE, 12*(4), e0174310. doi: 10.1371/journal.pone.0174310

482 Hays, J., McCawley, M., & Shonkoff, S. B. C. (2016). Public health implications of environmental noise associated with unconventional oil and gas development. *Science of the Total Environment, 580,* 448-556. doi: 10.1016/j.scitotenv.2016.11.118

483 Shonkoff, S. B. C., Jordan, P., Hays, J., Stringfellow, W. T., Wettstein, Z. S., Harrison, R., Sandelin, W., & McKone, T. E. (2015, July 9). Volume II, 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, Sacramento, CA. Retrieved from http://ccst.us/publications/2015/vol-II-chapter-6.pdf

- December 17, 2014 – The New York State Department of Health (NYS DOH) identified community impacts related to noise as a potential contributor to a variety of negative health impacts from drilling and fracking operations but noted that considerable scientific uncertainty remains on the issue of noise exposure per se as a risk factor. Noise, air pollution, traffic, vibration, odors, and nighttime lighting may all increase together as proximity to a drilling site decreases.[484]

- December 1, 2014 – Range Resources Corporation warned supervisors in Pennsylvania's Donegal Township that a "big burn" natural gas flare will continue for as long as a week and "will produce a continuous noise of as much as 95 decibels at the well pad. Sustained decibel levels between 90 and 95 can result in permanent hearing loss, but workers will be equipped with ear protection." Township supervisor Doug Teagarden expressed concern for residents, saying, "They told us the flare would be double the size of other well flares, and the noise will be like a siren on a firetruck…. There are houses within a couple of hundred yards of the well pad, and those folks are going to hear it."[485]

- November 6, 2014 – Sakthi Karunanithi, Director of Public Health in Lancashire, UK, reported on a Health Impact Assessment (HIA) of the two proposed shale gas exploration sites in Lancashire. Karunanithi's study determined that key risks to the health and well-being of the residents who live near the two proposed sites in Lancashire include stress and anxiety from uncertainty that could lead to "poor mental wellbeing," and noise-related health effects due to continuous drilling. The HIA also noted a lack of public trust and confidence.[486, 487]

- September 2014 – The Ohio Shale Country Listening Project, a collaborative effort to solicit, summarize, and share the perspectives and observations of those directly experiencing the shale gas build out in eastern Ohio, found that the more shale gas wells a community has, the less popular the oil and gas industry becomes. Many residents reported that they had not experienced the economic benefits promised by the oil and gas industry. They complained of increased rents and costs of gas and groceries, an influx of out-of-state workers, more vehicular accidents, road destruction from large trucks, and damaged landscape and cropland. Locals reported feeling less secure and more

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[484] New York State Department of Health. (2014, December 17). *A public health review of high volume hydraulic fracturing for shale gas development*. Retrieved from http://www.health.ny.gov/press/reports/docs/high_volume_hydraulic_fracturing.pdf

[485] Hopey, D. (2014, December 1). Gas flare to light up part of Washington County. *Pittsburgh Post Gazette.* Retrieved from http://powersource.post-gazette.com/powersource/companies-powersource/2014/12/01/Gas-flare-to-light-up-part-of-Washington-County/stories/201411250224

[486] Karunanithi, S. (2014, November 6). Potential health impacts of the proposed shale gas exploration sites in Lancashire. *Reported at a meeting of the Lancashire County Council Cabinet, Thursday, 6th November, 2014 at 2.00 pm in Cabinet Room 'B' - County Hall, Preston, Item 9 on the agenda(1-68).* Retrieved from http://council.lancashire.gov.uk/documents/b11435/Potential%20Health%20Impacts%20of%20the%20Proposed%20Shale%20Gas%20Exploration%20Sites%20in%20Lancashire%2006th-Nov-2014%2014.pdf?T=9

[487] Dunkley, E. (2014, November 7). Fracking in Lancashire 'may affect mental health', report finds. *BBC NEWS Lancashire.* Retrieved from http://www.bbc.com/news/uk-england-lancashire-29944212

financially strapped.[488]

- June 20, 2014 – In its discussion of "Oil and Gas Drilling/Development Impacts," the U.S. Office of Indian Energy and Economic Development detailed noise pollution from bulldozers, drill rigs, diesel engines, vehicular traffic, blasting, and flaring of gas. "If noise-producing activities occur near a residential area, noise levels from blasting, drilling, and other activities could exceed the U.S. Environmental Protection Agency (EPA) guidelines. The movement of heavy vehicles and drilling could result in frequent-to-continuous noise…. Drilling noise would occur continuously for 24 hours per day for one to two months or more depending on the depth of the formation."[489] Exposure to chronic noise can be deadly. The World Health Organization has documented the connection between environmental noise and health effects, including cardiovascular disease, cognitive impairment, sleep disturbance, and tinnitus. At least one million "healthy life years" are lost every year from traffic-related noise in the western part of Europe.[490]

- February 24, 2014 – In a review of the health effects from unconventional gas extraction published in the journal *Environmental Science & Technology*, leading researchers noted, "Noise exposure is a significant hazard due to the presence of multiple sources, including heavy equipment, compressors, and diesel powered generators. Loud continuous noise has health effects in working populations. It is likely that exposure to noise is substantial for many workers, and this is potentially important for health because drilling and servicing operations are exempt from some sections of the Occupational Safety and Health Administration noise standard." They noted that research should investigate stressors such as noise and light in the context of drilling and fracking operations in order to understand the overall effect of chemical and physical stressors together.[491]

- May 30, 2014 – The *Denver Post* reported that in order to help meet Colorado's noise limits for fracking operations in suburban neighborhoods (and partially block the glare of floodlights), Encana Oil and Gas erected 4-inch-thick polyvinyl walls up to 32 feet high and 800 feet long. Residents said that the plastic walls do not completely solve the problem.[492]

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[488] Ohio Organizing Collaborative (OOC)'s Communities United for Responsible Energy (CURE), with support from the Ohio Environmental Council (OEC), FracTracker.org, and Laborers Local 809 of Steubenville. (2014, September). Ohio Shale Country Listening Project. Retrieved from http://carrollconcernedcitizens.org/uploads/2014_Shale_Report__small_.pdf

[489] Oil and Gas Drilling/Development Impacts. (n.d.). *Oil and gas drilling/development impacts*. Retrieved from http://teeic.indianaffairs.gov/er/oilgas/impact/drilldev/index.htm

[490] Rodier, G. (2011, June 1). Burden of disease from environmental noise - Quantification of healthy life years lost in Europe. *WHO*. Retrieved from http://www.who.int/quantifying_ehimpacts/publications/e94888/en/

[491] Adgate, J. L., Goldstein, B. D., & McKenzie, L. M. (2014). Potential public health hazards, exposures and health effects from unconventional natural gas development. *Environmental Science & Technology 48*(15), 8307-20. doi: 10.1021/es404621d

[492] Finley, B. (2014, May 29). Oil and gas industry building giant walls to try to ease impact. *The Denver Post*. Retrieved from http://www.denverpost.com/ci_25859469/oil-and-gas-industry-building-giant-walls-try

- October 25, 2013 – An analysis of well location and census data by the *Wall Street Journal* revealed that at least 15.3 million Americans now live within a mile of a well that has been drilled since 2000. According to this investigation, the fracking boom has ushered in “unprecedented industrialization” of communities across wide swaths of the nation and, with it, “24/7” industrial noise, stadium lighting, earth-moving equipment, and truck traffic.[493]

- April 16, 2013 – In a presentation on oil field light pollution for a conference on “Sustainable Environment and Energy: Searching for Synergies,” Roland Dechesne of the Royal Astronomical Society of Canada described problems of “light trespass,” glare, and poorly-aimed fixtures in oil fields in Alberta. He described resulting “mass waterfowl mortality” linked to artificial illumination and other biochemical impacts of light pollution on wildlife, as well as the possibility of these effects on humans, including circadian disruption, melatonin suppression, and possible resulting hormonally-linked diseases.[494] Known to have ecological impacts, outdoor light pollution from drilling and fracking operations may also be linked to artificial light-associated health effects documented in humans, including breast cancer.[495]

- April 2013 – Led by the University of Pittsburgh Graduate School of Public Health, a study of community members living in proximity to Marcellus Shale drilling in Pennsylvania found adverse impacts to mental health, with stress the most frequently reported symptom. At least half of all respondents in each set of interviews reported these specific stressors, including: being taken advantage of; health concerns; concerns/complaints ignored; corruption; denied information or provided with false information. Many also reported the desire to move or leave community, estrangement from community, and financial damages. Researchers noted that stress can result in direct health impacts.[496] Notably, mounting evidence indicates that chronic stress magnifies individuals’ susceptibility to effects of pollution; for children, this interactive effect can begin during prenatal life.[497]

- September 7, 2011 – A study by researchers at Boise State University and Colorado State University at Fort Collins modeled the potential impacts of compressor station noise from oil and gas operations on Mesa Verde National Park in Colorado. The study found the sound of 64 compressors outside Mesa Verde elevated the sound level within the park by

[493] Gold, R. & McGinty, T. (2014, Oct. 25). Energy boom puts wells in America’s backyards. *The Wall Street Journal.* Retrieved from http://online.wsj.com/news/articles/SB10001424052702303672404579149432365326304
[494] Dechesne, R. (2013). Limiting oil field light pollution for safety and the environment. Sustainable Environment and Energy CPANS 2013 Conference. Retrieved from http://www.cpans.org/assets/Uploads/Presentations/NewFolder/Session-46Roland-Dechesne.pdf
[495] Chepesiuk, R. (2009). Missing the dark: Health effects of light pollution. *Environmental Health Perspectives,117*(1), A20–A27.
[496] Ferrar, K. J., Kriesky, J., Christen, C. L., Marshall, L. P., Malone, S. L., Sharma, R. K., Michanowicz, D. R., & Goldstein, B.D. (2013). Assessment and longitudinal analysis of health impacts and stressors perceived to result from unconventional shale gas development in the Marcellus Shale region. *International Journal of Occupational & Environmental Health*, *19*(2),104-112. doi: 10.1179/2049396713Y.0000000024
[497] Cooney, C.M. (2011). Stress–pollution interactions: An emerging issue in children’s health research. *Environmental Health Perspectives, 119*, a430-a435. http://dx.doi.org/10.1289/ehp.119-a430

34.8 decibels on average, and by 56.8 decibels on the side of the park located closest to the compressors. According to the EPA, 55 decibels is the highest “safe noise level” to avoid damage to the human ear.[498]

Earthquakes and seismic activity

A growing body of evidence from Ohio, Arkansas, Texas, Oklahoma, Kansas, and Colorado links fracking wastewater injection (disposal) wells to earthquakes of magnitudes as high as 5.8, in addition to swarms of minor earthquakes. Both the U.S. Geological Survey (USGS) and state geological agencies such as the Oklahoma Geological Survey now acknowledge that earthquakes can be caused by wastewater injection. Many recent studies focus on the mechanical ability of pressurized fluids to trigger seismic activity by unclamping stressed faults. In some cases, and especially in Canada, the fracking process itself has been linked to earthquakes as significant as magnitude 4.4. Emerging evidence suggests that risk of earthquakes can continue to rise for years after waste injection and cannot be prevented through “proper” fracking protocols or by solely limiting the rate or volume of injected fluid. The question of what to do with fracking wastewater remains a problem with no viable, safe solution.

- November 24, 2017 – A team of geologists confirmed conclusively that recent earthquakes in Texas’ Fort Worth Basin were induced by underground injection of fracking waste that caused deep, critically stressed faults to slip.[499] The authors of this study employed a classical structural geology analysis that relied on high-resolution seismic reflection imaging, described in an interview with geophysical researcher Maria Magnani as “a little bit like an ultrasound.”[500] Maps of the seismically active faults in the Fort Worth Basin show no evidence of previous motion over the past millions of years and instead have been “sleeping” for approximately the past 300 million years until “awakened” at the start of the 2008 earthquake swarm associated temporally with extensive wastewater injection activities.[501]

- October 21, 2017 – Extending the findings of two previous studies, an investigation of earthquakes in the Raton Basin along the border of New Mexico and Colorado identified

[498] Barber, J. R., Burdett, C.L., Reed, S. E., Warner, K.A., Formichella, C., Crooks, K.R., Theobald, D.M., &. Fristrup, K. M. (2011). Anthropogenic noise exposure in protected natural areas: estimating the scale of ecological consequences. *Landscape Ecology, 26*(9), 1281-1295.
[499] Magnani, M. B., Blanpied, M. L., DeShon, H. R., & Hornbach, M. J. (2017). Discriminating between natural versus induced seismicity from long-term deformation history of intraplate faults. *Science Advances, 3*(11), e1701593. doi: 10.1126/sciadv.1701593
[500] Guarino, B. (2017, November 24). Oil and gas industry is causing Texas earthquakes, a ‘landmark’ study suggests. *The Washington Post.* Retrieved from https://www.washingtonpost.com/news/speaking-of-science/wp/2017/11/24/fracking-and-other-human-activities-are-causing-texas-earthquakes-study-suggests/?tid=ss_tw&utm_term=.02bfff4181f1
[501] Kuchment, A. (2017, November 24). Drilling reawakens sleeping faults in Texas, leads to earthquakes. *Scientific American.* Retrieved from https://www.scientificamerican.com/article/drilling-reawakens-sleeping-faults-in-texas-leads-to-earthquakes/?utm_source=newsletter&utm_medium=email&utm_campaign=weekly-review&utm_content=link&utm_term=2017-11-29_featured-this-week

wastewater injection wells as the cause of the quakes and identified a mechanism.[502] All together, the location of the earthquakes, modeled pore pressures, and the direct correlation between cumulative volume of injected waste in nearby wells and the number of quakes show that seismicity in the Raton Basin is likely induced, and that elevated pore pressures deep underground are "well above earthquake-triggering thresholds."[503]

- September 14, 2017 – An investigation by *Politico* found that the U.S. crude oil storage hub in Cushing, Oklahoma—the world's largest store of oil—was not designed with seismic considerations in mind, nor are there seismic regulations in place for its 250,000-barrel oil tanks, which are under the purview of the Department of Transportation's Pipeline and Hazardous Materials Safety Administration. Central Oklahoma, where Cushing is located, became seismically active about five years ago when "wastewater injection and other fracking-related activities changed the seismic face of Oklahoma in dramatic fashion."[504] [See also entry below for November 8, 2016.]

- May 3, 2017 – Studying two patterns of fracking waste injection in Oklahoma, geologists observed a large, unexpected impact on seismic activity at sites where injection rates drastically changed in recent years, as compared with those whose injection volumes held steady. They demonstrated that, in addition to direct pore pressure effects, deformations due to fluid flows ("poroelastic effects") play an important role in generating earthquake activity. Elevated risks for earthquakes can persist years after fracking waste is injected underground. Their findings also showed that the "magnitude of the initial change in injection rate is particularly important, but the opposite effect occurs in the transition to zero injection" (i.e., shut-in or closing a well). This result implies that "in certain faulting regimes it is theoretically possible to mitigate damaging effects of rapid shut-in by carefully tapering injection rates."[505] Geophysicist Andrew Barbour, lead author of the study, said that fluctuating injection rates likely have a "profound effect" on earthquake risk.[506] These findings suggest that the 2016 Pawnee earthquake, the strongest earthquake ever recorded in Oklahoma, may have been triggered by pulses of underground oil and gas activity years earlier.[507]

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[502] Nakai, J. S., Weingarten, M., Sheehan, A. F., Bilek, S. L., & Ge, S. (2017). A possible causative mechanism of Raton Basin, New Mexico and Colorado earthquakes using recent seismicity patterns and pore pressure modeling. *Journal of Geophysical Research: Solid Earth, 122.* doi: 10.1002/2017JB014415

[503] Scott, J. (2017, October 24). Raton Basin earthquakes linked to oil and gas fluid injections. *University of Colorado Boulder.* Retrieved from https://www.colorado.edu/today/2017/10/24/raton-basin-earthquakes-linked-oil-and-gas-fluid-injections

[504] Ogrocki, S. (2017, September 24). How man-made earthquakes could cripple the U.S. economy. *Politico.* Retrieved from http://www.politico.com/magazine/story/2017/09/14/earthquakes-oil-us-economy-fracking-215602

[505] Barbour, A. J., Norbeck, J. H., & Rubinstein, J. L. (2017). The effects of varying injection rates in Osage County, Oklahoma, on the 2016 Mw 5.8 Pawnee earthquake. *Seismological Research Letters, 88*(4), 1040-1053. Doi: 10.1785/0220170003

[506] Jones, C. (2017, May 7). USGS study 'strongly suggests' short-term variations in disposal volumes served as trigger for Pawnee earthquake. *Tulsa World.* Retrieved from http://www.tulsaworld.com/earthquakes/usgs-study-strongly-suggests-short-term-variations-in-disposal-volumes/article_97de08d5-9327-505d-8b51-adbc716d6c69.html

[507] Wertz, J. (2017, May 4). Study links pulse of oil-field wastewater to Oklahoma's strongest earthquake. *StateImpact Oklahoma.* Retrieved from https://stateimpact.npr.org/oklahoma/2017/05/04/study-links-pulse-of-oil-field-wastewater-to-oklahomas-strongest-earthquake/

- April 27, 2017 – Recognizing that increased seismicity from both hydraulic fracturing and underground disposal of fracking wastewater poses a hazard to critical infrastructure, such as large dams, a Canadian geologist proposed strategies to keep the likelihood of high-failure consequences under one per ten thousand per year.[508] The primary strategy is the creation of "no frack" exclusion zones with a 5-kilometer (3.1 mile) radius that would surround vulnerable, critical facilities. In a larger ring beyond the exclusion zone, to approximately 25 kilometers (15.5 miles), monitoring and response protocols would be used.[509]

- March 1, 2017 – Despite decreases of up to 40 percent in the volume of fracking wastewater injected underground in Oklahoma, researchers from the USGS Earthquake Hazard Program forecasted that seismic hazards would remain significantly elevated there throughout 2017, with the odds of damage from induced earthquakes within the next year "similar to that of natural earthquakes in high-hazard areas of California." About three million people in Oklahoma and southern Kansas now live with continuing increased potential for damaging shaking from induced seismicity."[510] According to Mark Petersen, chief of the USGS National Seismic Hazard Mapping Project, the hazard risk remains "hundreds of times higher than before man-made activity began."[511]

- February 17, 2017 – Pennsylvania's Department of Environment Protection (PA DEP) announced that a series of small earthquakes in Lawrence County had been induced by fracturing of wells in the Utica Shale.[512] PA DEP officials held a webinar to discuss the situation and formulate "procedures to reduce seismic risk going forward," but no formal report or regulatory changes have yet been made public.[513]

- December 20, 2016 – In an attempt to reduced the risk of earthquakes caused directly by fracking, the Oklahoma Corporation Commission's Oil and Gas Conservation Division introduced monitoring and response guidelines that include provisions requiring oil producers to "implement mitigation plans following an earthquake of magnitude 2.5 or more and to suspend operations following a quake of magnitude 3.5 or greater."[514]

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508 Atkinson, G. M. (2017). Strategies to prevent damage to critical infrastructure due to induced seismicity. *FACETS, 2,* 374–394. doi: 10.1139/facets-2017-0013
509 Nikiforuk, A. (2017, July 24). Earthquake expert proposes 'no frack zone' around critical infrastructure. *The Tyee.* Retrieved from https://thetyee.ca/News/2017/07/24/Critical-Infrastructure-No-Frack-Zone/
510 Petersen, M. D., Mueller, C. S., Moschetti, M. P., Hoover, S. M., Shumway, A. M., McNamara, D. E., … Rukstales, K.S., (2017). 2017 one-year seismic-hazard forecast for the central and eastern United States from induced and natural earthquakes. *Seismological Research Letters, 88*(3). doi: 10.1785/0220170005
511 Wilmoth, A. (2017, March 1). Oklahoma considered at 'significant potential' for damaging earthquakes. *News OK.* Retrieved from http://newsok.com/article/5539785https://mail.google.com/mail/u/0/
512 Legere, L. (2017, February 17). DEP links Lawrence County earthquakes to fracking. *Pittsburgh Post-Gazette.* Retrieved from http://powersource.post-gazette.com/powersource/policy-powersource/2017/02/16/DEP-Pennsylvania-Lawrence-County-earthquakes-appear-linked-to-fracking-Hilcorp-Energy/stories/201702160176
513 Pennsylvania Department of Environmental Protection. (2017, February 17). *Advisory – Department of Environmental Protection to hold webinar on 2016 Lawrence County seismic events.* Retrieved from http://www.ahs.dep.pa.gov/NewsRoomPublic/articleviewer.aspx?id=21145&typeid=1
514 Hampton, L. (2016, December 20). Oklahoma's new fracking guidelines aim to reduce quake risk. *Reuters.* Retrieved from https://www.reuters.com/article/us-oklahoma-quake-rules/oklahomas-new-fracking-guidelines-aim-to-reduce-quake-risk-idUSKBN1492R6

- November 17, 2016 – A study of fault activation found a connection between fracking and earthquake activity in a region of Alberta, Canada that had previously been seismically quiescent. The researchers demonstrated that new earthquake activity in the Fox Creek area was tightly spatially correlated with hydraulic fracturing activities. Their findings further suggested that seismic activity resulted from "stress changes due to the elastic response of the rockmass to hydraulic fracturing," as well as "pore-pressure changes due to fluid diffusion along a permeable fault zone."[515] In contrast to the central United States, where induced seismic activity is primarily caused by massive underground disposal of fracking waste, these findings pointed to the fracking process itself as the trigger. In an interview with the *New York Times,* co-author David Eaton compared fracking to a series of "small underground explosions" that travel into the rock formation and "rapidly change the stress patterns within." These stress changes can be sufficient to trigger a slip at a critically stressed, previously undetected fault.[516]

- November 17, 2016 – An investigation by the *Dallas Morning News* chronicled a pattern of corruption and regulatory failings at the Texas Railroad Commission, the state agency charged with overseeing the oil and gas industry, in its disregard of evidence linking fracking waste disposal to earthquakes in North Texas.[517]

- November 8, 2016 – On November 6, 2016, a magnitude 5.0 earthquake struck Cushing, Oklahoma near the oil hub where 60 million barrels of crude oil were stored. The quake injured one, damaged more than 40 buildings, closed a school, and triggered evacuations. Oil infrastructure was not damaged.[518] [See also entry above for September 14, 2017.]

- October 7, 2016 – The EPA recommended a moratorium on the underground injection of fracking wastewater in certain earthquake-prone parts of Oklahoma after a 5.8 earthquake struck near Pawnee on September 3, 2016.[519] The strongest in Oklahoma's history, the Pawnee earthquake was felt by residents in five states and prompted a state of emergency declaration as well as an order from state regulators to shut down 67 wastewater disposal wells in the area.[520, 521]

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[515] Bao, X., & Eaton, D. W. (2016). Fault activation by hydraulic fracturing in western Canada. *Science,* aag2583. doi: 10.1126/science.aag2583
[516] Fountain, H. (2016, November 17). In Canada, a direct link between fracking and earthquakes. *The New York Times.* Retrieved from https://www.nytimes.com/2016/11/18/science/fracking-earthquakes-alberta-canada.html?mtrref=www.google.com&gwh=535A4330D3C30EF6934E1739AC62D5DA&gwt=pay
[517] Thompson, S., & Kuchment, A. (2016, November 17). Seismic denial: Why Texas won't admit fracking wastewater is causing earthquakes. *Dallas Morning News.* Retrieved from http://interactives.dallasnews.com/2016/seismic-denial/#_ga=2.247990020.202656599.1515906987-1750807308.1515724730
[518] Philips, M. (2016, November 8). Why Oklahoma can't turn off its earthquakes. *Bloomberg Businessweek.* Retrieved from http://www.bloomberg.com/news/articles/2016-11-08/why-oklahoma-can-t-turn-off-its-earthquakes
[519] Soraghan, M. (2016, October 7). EPA suggests partial disposal moratorium in Okla. *E&E EnergyWire.* Retrieved from http://www.eenews.net/energywire/stories/1060043991
[520] U.S. Geological Survey. (2016, September 3). M5.8 – 14 km NW of Pawnee, Oklahoma. Retrieved from http://earthquake.usgs.gov/earthquakes/eventpage/us10006jxs#executive
[521] Oklahoma Corporation Commission. (2016, September 12). *Latest action regarding Pawnee area* [Press release]. Retrieved from https://www.occeweb.com/News/2016/09-12-16Pawnee%20Advisory.pdf

- September 22, 2016 – A study using satellite-based radar imagery found that the earth's surface rose, by 3 millimeters per year, in areas of fracking waste injection. Underground pore pressures for this area exceeded those known to trigger earthquakes. These findings provide proof that the migration of fracking wastewater into faults increased pressures in ways that triggered a 4.8 magnitude earthquake in east Texas in 2012. The researchers emphasized that pore pressure elevation and propagation from fracking wastewater injection may evolve over periods of months to years before affecting critically stressed faults.[522]

- September 14, 2016 – Researchers from the USGS used a newly deployed seismic monitoring network to document the rupture of a fault plane that set off a magnitude 4.9 earthquake in Milan, Kansas in 2014, immediately following a rapid increase in fracking wastewater injection nearby.[523]

- May 2016 – In a study that has "far-reaching implications for assessment of induced-seismicity hazards," a Canadian team of researchers determined that hydraulic fracturing itself is linked to earthquake swarms in western Canada, in contrast to the central United States where disposal of fracking waste is the cause of most induced seismicity. Furthermore, lowering the volume of injected fluid may not be sufficient to prevent quakes. In the Western Canada Sedimentary Basin, "it appears that the maximum-observed magnitude of events associated with hydraulic fracturing may exceed the prediction of an often-cited relationship between the volume of injected fluid and the maximum expected magnitude…. Rather, we propose that the size of the available fault surface that is in a critical state of stress may control the maximum magnitude…. Our results indicate that the maximum magnitude of induced events for hydraulic fracturing may not be well correlated with net injected fluid volume."[524]

- April 29, 2016 – Five small earthquakes in one 24-hour period originated in an area in Lawrence County, Pennsylvania near a fracking operation that was drilling into the deep Utica Shale at the time. Quoted in the *Pittsburg Post-Gazette*, researchers noted that it is very difficult for operators to avoid areas with faults because their locations are very often unknown.[525]

- March 28, 2016 – A summary of the evidence linking drilling and fracking activities to earthquakes appeared in *Scientific American.* Emerging data suggests that pressure

[522] Shirzaei, M., Ellsworth, W. L., Tiampo, K. F., Gonzalez, P. J., & Manga, M. (2016). Surface uplift and time-dependent seismic hazard due to fluid injection in eastern Texas. *Science, 353*(6306). doi: 10.1126/science.aag0262
[523] Choy, G. L., Rubenstein, J. L., Yeck, W. L., McNamara, D. E., Mueller, C. S., & Boyd, O. S. (2016). A rare moderate-sized (Mw 4.9) earthquake in Kansas: Rupture process of the Milan, Kansas, earthquake of 12 November 2014 and its relationship to fluid injection. *Seismological Research Letters, 87.* doi: 10.1785/0220160100
[524] Atkinson, G. M., Eaton, D. W., Ghofrani, H., Walker, D., Cheadle, B., Schultz, R. … Kao, H. (2016). Hydraulic fracturing and seismicity in the Western Canada Sedimentary Basin. *Seismological Research Letters, 87(*3). doi: 10.1785/0220150263
[525] Legere, L. (2016, April 29). State studying link between fracking, Lawrence County earthquakes. *Pittsburgh Post-Gazette.* Retrieved from http://powersource.post-gazette.com/powersource/companies/2016/04/29/State-studying-link-between-fracking-and-Lawrence-County-earthquakes/stories/201604290099

changes caused by fracking wastewater injection can migrate for years before encountering a geological fault and altering stresses in ways that allow for slippage. In this way, earthquake risks can spread out over both time and space—traveling for miles beyond the disposal well and persisting for a decade or more as injected fluids travel underground. In spite of increasing scientific clarity about these mechanisms, regulators have been slow to respond.[526]

- February 1, 2016 – An article in the *Texas Journal of Oil, Gas, and Energy Law* exhaustively reviewed the literature on earthquake activity in areas of six states (Arkansas, Colorado, Kansas, Ohio, Oklahoma, and Texas) where fracking takes place or drilling wastes are disposed underground and concluded that courts should impose strict liability for earthquake damage caused either by fracking itself or by the underground injection of fracking fluids. "Earthquakes sometimes occur when subsurface formations are properly fractured. Likewise, the risk of earthquake damage is not substantially mitigated by the exercise of due care when frack fluids are injected into the ground."[527]

- January 22, 2016 – An international research team investigated a swarm of earthquakes in California's Central Valley that occurred in 2005. Using hydrogeological modeling, the researchers concluded that the underground injection of wastewater from oil drilling operations had contributed to seismicity via changes in localized pressures along an active fault.[528]

- January 12, 2016 – As reported by *CBC News*, a Canadian regulatory agency ordered a drilling and fracking operation in northwestern Alberta to shut down after a magnitude 4.8 earthquake struck nearby. The operator was fracking at the time the earthquake happened.[529]

- November 15, 2015 – A spokesperson for the Oklahoma Corporation Commission, which regulates the oil and gas industry in the state, said that Oklahoma now leads the world in earthquake frequency.[530]

- October 29, 2015 – The Kansas Corporation Commission extended limits on the injection of wastewater from fracking operations after a drop in the frequency of earthquakes that

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[526] Kuchment, A. (2016, March 28). Drilling for earthquakes. *Scientific American.* Retrieved from https://www.scientificamerican.com/article/drilling-for-earthquakes/
[527] Watson, B. A. (2016). Fracking and cracking: Strict liability for earthquake damage due to wastewater injection and hydraulic fracturing. *Texas Journal of Oil, Gas and Energy Law, 11*(1). Retrieved from http://ssrn.com/abstract=2735862
[528] Goebel, T. H. W., Hosseini, S. M., Cappa, F., Hauksson, E., Ampuero, J. P., Aminzadeh, F., & Saleeby J. B. (2016). Wastewater disposal and earthquake swarm activity at the southern end of the Central Valley, California. *Geophysical Research Letters, 43*. doi: 10.1002/2015GL066948
[529] *CBC News*. (2016, January 12). Fox Creek fracking operation closed indefinitely after earthquake. Retrieved from http://www.cbc.ca/news/canada/edmonton/fox-creek-fracking-operation-closed-indefinitely-after-earthquake-1.3400605
[530] Miller, J. (2016, November 10). Oklahoma world's no. 1 earthquake area. *Enid News and Eagle.* Retrieved from http://www.enidnews.com/news/local_news/oklahoma-world-s-no-earthquake-area/article_69b145b8-c180-5065-8f99-b2a7ec7ce913.html

followed an earlier order to limit such injections.[531] Between 2013 and October 2015, Kansas recorded more than 200 earthquakes. Before that, the average rate was one earthquake every two years.

- October 23, 2015 – *Bloomberg* explored the national security risks that fracking-induced earthquakes in Oklahoma create for the nation's largest oil storage hub in Cushing, where aboveground tanks hold more than 60 million barrels of crude oil and serve as a way station for oil from North Dakota's Bakken Shale as it heads to Gulf Coast refineries. Earthquake swarms have hit within a few miles of Cushing and may be harbingers of larger quakes in the future. "Now that quakes appear to have migrated closer to Cushing, the issue of what to do about them has morphed from a state issue to one of national security…. Not only is Cushing crucial to the financial side of the oil market, it is integral to the way physical crude flows around the country."[532]

- September 21, 2015 – An international team of geologists investigated possible causes of the Lusi mudflow, which began suddenly in 2006 when mud began erupting from the ground in a volcano-like fashion in an urban area of Java in Indonesia. The ongoing disaster has, as of 2015, displaced 39,700 people and cost nearly $3 billion in damages and disaster management. Looking at data on the emissions of subsurface gases before and after the eruption began, the team concluded that the likely cause was nearby gas drilling that forced fluid into the clay layer via the open well. "We therefore conclude that the Lusi eruption was not triggered naturally but was instead the consequence of drilling operations."[533] In interviews with the *New York Times*, lead author Mark Tinjay said, "We are now 99 percent certain that the drilling hypothesis is valid," while other experts who were not authors of the paper expressed less certainty.[534]

- July 27, 2015 – During a seven-day period in late July, the state of Oklahoma experienced 40 earthquakes. According to the USGS, three registered above magnitude 4.0, one of which was strong enough to be felt by 1.9 million people, including residents of several surrounding states.[535] In response, gas and oil operators voluntarily shut down two nearby wastewater injection wells and reduced operations by half at a third well.[536] According to the Oklahoma Geological Survey, the recent quakes are occurring along a fault line that extends north of Oklahoma City and signal greater potential for a larger

[531] Kansas Corporation Commission. (2015, October 29). *Kansas Corporation Commission approves order extending wastewater injection limits.* [Press release.] Retrieved from http://www.kcc.state.ks.us/pi/press/15-13.htm
[532] Phillips, M. (2015, October 23). Oklahoma earthquakes are a national security threat. *Bloomberg*. Retrieved from http://www.bloomberg.com/news/articles/2015-10-23/oklahoma-earthquakes-are-a-national-security-threat
[533] Tingay, M. R. P., Rudolph, M. L., Manga, M., Davies, R. J., & Wang, C-Y. (2015). Initiation of the Lusi mudflow disaster. *Nature Geoscience, 8*. doi:10.1038/ngeo2472
[534] Nuwer, R. (2015, September 21). Indonesia's 'mud volcano' and nine years of debate about its muck. *The New York Times*. Retrieved from http://www.nytimes.com/2015/09/22/science/9-years-of-muck-mud-and-debate-in-java.html?rref=collection%2Fsectioncollection%2Fscience&_r=0
[535] U.S. Geological Survey, (2015, July 27). M4.5 – 6 km NNE of Crescent, Oklahoma. Retrieved from http://earthquake.usgs.gov/earthquakes/eventpage/us200030gd#impact_pager
[536] Oklahoma Corporation Commission (2015, July 28). Media advisory: new actions taken in response to earthquake activity in the Crescent area. Retrieved from http://www.occeweb.com/News/Crescent%20wells.pdf

earthquake.[537] Ten days before the voluntary shutdowns, the Oklahoma Corporation Commission, which regulates the oil and gas industry, put 211 wastewater disposal wells under extra review.[538] The next month, Oklahoma regulators, acknowledging that previous efforts have been unsuccessful in reducing seismic activity, asked operators of 23 injection wells to decrease the amount of wastewater injected by 38 percent and signaled that more sweeping regulatory actions may follow.[539]

- July 1, 2015 – Two researchers, from the USGS and the Geological Survey of Canada, offered a summary of the history, basic geology, and engineering of fracking fluid injection and induced seismicity. Noting that since 2001 Oklahoma had experienced two earthquakes of very large magnitude (5.0 and 5.3), the authors called for "a detailed understanding of the physical processes involved in inducing large magnitude events and a detailed understanding of the geology and hydrology at the site of the earthquakes." They also noted that many important parameters are either unknown or not easily constrained, making it "difficult to determine the wells that will induce earthquakes and those that will not."[540]

- June 30, 2015 – The Oklahoma Supreme Court ruled that homeowners who have sustained injuries or property damage that they believe is due to earthquakes caused by oil and gas operations can sue for damages in state trial courts. The number of earthquakes with magnitude 3.0 or higher has skyrocketed in Oklahoma, with 1,100 predicted to occur in 2015. Earlier this year, scientists at the state's geological survey reversed prior views and embraced the conclusion that the majority of the recent earthquakes in central and north-central Oklahoma were "very likely triggered" by underground wastewater disposal. Industry lawyers have complained that liability for such damages will be economically unsustainable. A separate class action lawsuit is planned.[541]

- June 19, 2015 – By compiling a database of 187,570 injection wells in the central and eastern United States, University of Colorado Boulder and USGS researchers were able to test for associations between fracking waste disposal and earthquakes. Results showed far more injection wells were potentially related to earthquakes than had previously been realized, and active disposal-only wells were more than 1.5 times more likely than active oil extraction wells to be associated with an earthquake. In addition, high-rate injection

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[537] Murphy, S. (2015, July 28). 2 injection wells shut down after Oklahoma quakes. *Associated Press.* Retrieved from http://www.santacruzsentinel.com/business/20150728/2-injection-wells-shut-down-after-oklahoma-quakes
[538] Oklahoma Corporation Commission (2015, July 17). *OCC announces next step in continuing response to earthquake concerns, 200-plus more disposal wells added to action list* [Press release]. Retrieved from http://www.occeweb.com/News/DIRECTIVE-2.pdf
[539] Wines, M. (2015, August 4). Oklahoma acts to limit earthquake risk at oil and gas wells. *The New York Times.* Retrieved from http://www.nytimes.com/2015/08/05/us/oklahoma-acts-to-limit-earthquake-risk-at-oil-and-gas-wells.html?_r=0
[540] Rubenstein, J. L., & Mahani, A. B. (2015). Myths and facts on wastewater injection, hydraulic fracturing, enhanced oil recovery, and induced seismicity. *Seismological Research Letters, 86*(4), 1060-1067. doi: 10.1785/0220150067
[541] Oppel Jr., R.A. (2015, June 30). Oklahoma court rules homeowners can sue oil companies over quakes. *The New York Times*. Retrieved from http://www.nytimes.com/2015/07/01/us/oklahoma-court-rules-homeowners-can-sue-oil-companies-over-quakes.html?emc=edit_tnt_20150630&nlid=66402583&tntemail0=y&_r=0

wells, receiving more than 300,000 barrels of fluid per month, were much more likely than lower-rate wells to be associated with an earthquake, while other factors, including wellhead injection pressure, appeared unrelated to increased earthquake activity. The study called for managing injection rates as "a useful tool to minimize the likelihood of induced earthquakes." The researchers did not address the impact of hydrofracturing activities *per se* as a potential confounding variable.[542, 543]

- June 18, 2015 – Close examination of several areas in Oklahoma by Stanford University geophysicists revealed that dramatic increases in recent earthquake activity followed 5- to 10-fold increases in deep-well injection of briny "produced water," the highly salty fluid that rises to the surface from water-bearing oil reserves and requires disposal. The rate of earthquake occurrence, which began to increase in 2009, is now 600 times higher than it was before the onset of widespread fracking in the state. The disposal of this type of waste in Oklahoma mostly occurs via injection into geological formations that appear to be in hydraulic communication with potentially active faults in the crystalline basement. The study proposed that increasing pressure, spreading away from injection wells over time, could eventually trigger slips on critically stressed faults, resulting in earthquake activity. It is likely that, "even if injection from many wells were to stop immediately, seismicity would continue as pressure continues to spread out from past injection."[544]

- June 12, 2015 – Researchers in France uncovered an unexpected mechanism by which subsurface fluid injections, such as those used in high volume hydrofracturing, can cause earthquakes. They found that injection of pressurized water can cause fault lines to "creep" rather than slip suddenly as occurs during earthquakes. Earthquakes did follow this slow movement but took place in a portion of the fault outside the pressurized zone. This research demonstrated that subsurface injection of fluids under pressure can cause primary gradual slippage of fault planes leading to secondary sudden seismic activity.[545, 546]

- June 11, 2015 – As reported by the Vancouver news magazine *The Tyee,* seismic events of magnitude greater than 2.0 (but less than 4.0) in the Fox Creek area were reported in Alberta, Canada since the initiation in February of a novel "traffic light system" for responding to measured seismic activity. The system requires varying responses according to the magnitude of the event, ranging from no action up to ceasing operations and informing the Alberta Energy Regulator for events at magnitudes greater than 4.0. Experts noted that the system does not work well when the largest event in the sequence

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542 Weingarten, M. Ge, S., Godt, J. W., Bekins, B. A., & Rubinstein, J. L. (2015). High-rate injection is associated with the increase in U.S. mid-continent seismicity. *Science, 348*(6241), 1336-1340. doi: 10.1126/science.aab1345
543 Rosen, J. (2015). Pumped up to rumble: Massive studies of wastewater injection wells show fast pumping raises earthquake risk. *Science, 368*(6241),1299. doi: 10.1126/science.aac6857
544 Wall, F.R. III, & Zobakc, M.D. (2015). Oklahoma's recent earthquakes and saltwater disposal. *Science Advances, 1*(5), e1500195.
545 Guglielmi, Y., Cappa, F., Avouac, J.-P., Henry, P., & Elsworth, D. (2015). Seismicity triggered by fluid injection–induced aseismic slip. *Science*, *348*(6240), 1224-1226. doi: 10.1126/science.aab0476
546 Johnson, S. K. (2015, June 11). Making tiny earthquakes to understand fracking-driven quakes. *arstechnica.* Retrieved from http://arstechnica.com/science/2015/06/making-tiny-earthquakes-to-understand-fracking-driven-quakes/

is the first event. Moreover, once a sequence of earthquakes is initiated, the sequence may continue, sometimes with larger earthquakes, long after potentially causally related drilling or injection activities have ceased.[547]

- June 1, 2015 – In a data-rich presentation, a team of researchers from St. Louis University, Colorado State University, and USGS concluded that "a fundamental change in the earthquake-triggering process has occurred" in central Oklahoma. Using advanced field monitoring and high-performance software, computer models illustrate active earthquake sequences associated with long fault structures "that might be capable of supporting large earthquakes (M 5 to 6)" and possibly cascades of earthquakes, which could occur near population centers and expensive infrastructure associated with the oil and gas industry, such as a large underground crude-oil storage facility.[548]

- May 11, 2015 – A series of directives from the Oklahoma Corporation Commission revealed a slowly evolving approach to the regulation of disposal well operations in that state, and the gradual tightening of a "traffic light system" introduced in 2013 to determine whether disposal wells for fracking waste should be permitted, permitted only with special restrictions and requirements, or not permitted, in light of the now-proven connection between the injection of liquid waste and the soaring frequency of earthquakes in Oklahoma. Since 2013, earthquake activity in Oklahoma has continued to increase in rate and intensity.[549, 550]

- April 23, 2015 – In a first-of-its-kind approach, the USGS is updating its National Seismic Hazard Model to address the rapidly increasing, highly variable, and difficult-to-predict hazards of induced earthquakes.[551] This initial report identified 17 areas within eight states (Alabama, Arkansas, Colorado, Kansas, New Mexico, Ohio, Oklahoma, and Texas) with increased rates of induced seismicity, including many areas experiencing earthquakes of large magnitude.[552] Two days before the release of this report, Oklahoma's state government acknowledged for the first time that wastewater disposal related to oil and gas drilling is "very likely" to blame for the huge surge of earthquakes

[547] Nikiforuk, A. (2015, June 11). More industry linked earthquakes recorded in Alberta. *TheTyee.ca.* Retrieved from http://thetyee.ca/News/2015/06/11/More-Fracking-Earthquakes/
[548] McNamara, D. E., Rubinstein, J. L., Myers, E., Smoczyk, G., Benz, H. M., Williams, R. A., . . . Earle, P. (2015). Efforts to monitor and characterize the recent increasing seismicity in central Oklahoma. *The Leading Edge, 34*(6). doi: 10.1190/tle34060628.1
[549] Oklahoma Corporation Commission, Oil & Gas Conservation Division. (2015, May 11). Media advisory: Ongoing OCC earthquake response. Retrieved from http://www.occeweb.com/News/2015/ADVISORY%20-%20TRAFFIC%20LIGHT.pdf
[550] Oklahoma Corporation Commission. (n.d.) Seismic statement. Retrieved from http://www.occ.state.ok.us/SeismicStatementB.pdf
[551] Petersen, M. D., Mueller, C. S., Moschetti, M. P., Hoover, S. M., Rubinstein, J. L., Llenos, A. L., . . . Anderson, J. G. (2015). Incorporating induced seismicity in the 2014 United States National Seismic Hazard Model—Results of 2014 workshop and sensitivity studies: U.S. Geological Survey Open-File Report 2015–1070. Retrieved from http://dx.doi.org/10.3133/ofr20151070
[552] USGS. (2015, April 23). New insight on ground shaking from man-made earthquakes. *USGS Newsroom.* Retrieved from http://www.usgs.gov/newsroom/article_pf.asp?ID=4202

in many areas of Oklahoma, the *New York Times* reported.[553] Several states have developed protocols to shut down existing wells and halt drilling of new disposal wells following an upsurge in earthquake activity.

- April 21, 2015 – Analyzing the unusual increase of seismicity in north Texas since 2008, researchers from Southern Methodist University, the USGS, and University of Texas at Austin concluded that observed earthquake swarms were associated both with extraction (of gas and brine formation waters) and injection (of fracking wastewater), via significant stress changes at earthquake depths. The research team noted that baseline pressure monitoring data, though easy to obtain and routinely collected by industry at well sites, were currently "neither required nor typically available for analysis." Greater transparency and cooperation in regional seismic monitoring is needed to generate more comprehensive data sets that are necessary for robust earthquake hazard analysis, they asserted.[554, 555]

- April 21, 2015 – In a statement reporting on an increase in earthquakes in Oklahoma of greater than magnitude 3.0 from less than two per year historically to over two per day in 2015, the Oklahoma Geological Society acknowledged that that the primary, suspected source of "triggered seismicity" is the injection and disposal of produced water associated with oil and gas production.[556]

- March 30, 2015 – *Bloomberg Business* reported that Oklahoma state seismologists had received pressure from oil industry representatives to downplay the evidence linking fracking wastewater disposal to the soaring frequency of earthquakes in the state.[557]

- March 6, 2015 – A careful and detailed analysis of historical data coupled with onsite, real-time measurements of seismic activity in central Oklahoma via rapidly deployed seismic sensors revealed that reactivated ancient faults responsible for thousands of earthquakes in Oklahoma are capable of causing larger seismic events. Current hazard maps did not include induced seismicity and therefore underestimate earthquake hazard, the USGS reported. Until new hazard maps become available, providing information about the type, length, and location of these reactivated faults could provide guidance to the oil and gas industry and help inform public policy decisions.[558] In addition, noted lead

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[553] Pérez-Peña, R. (2015, April 23). U.S. maps pinpoint earthquakes linked to quest for oil and gas. *The New York Times.* Retrieved from http://www.nytimes.com/2015/04/24/us/us-maps-areas-of-increased-earthquakes-from-human-activity.html?ref=us&_r=1

[554] Hornbach, M. J., DeShon, H. R., Ellsworth, W. L., Stump, B. W., Hayward, C., Frohlich, C., . . . Luetgert, J.H. (2015). Causal factors for seismicity near Azle, Texas. *Nature Communications, 6*(6728). doi: 10.1038/ncomms7728

[555] Richter, M. (2015, April 21). Small north Texas quakes likely linked to oil, gas operations – study. *Reuters.* Retrieved from http://www.reuters.com/article/2015/04/21/us-usa-texas-earthquake-idUSKBN0NC2DY20150421

[556] Andrews, R.D. & Holland, A. (2015, April 21). Statement on Oklahoma Seismicity. Retrieved from http://wichita.ogs.ou.edu/documents/OGS_Statement-Earthquakes-4-21-15.pdf

[557] Elgin, B., & Phillips, M. (2015, March 30). Big oil pressured scientists over fracking wastewater's link to quakes. *Bloomberg Business.* Retrieved from http://www.bloomberg.com/news/articles/2015-03-30/big-oil-pressured-scientists-over-fracking-wastewater-s-link-to-quakes

[558] McNamara, D. E., Benz, H. M., Herrmann, R. B., Bergman, E. A., Earle, P., Holland, A., Baldwin, R., & Gassner, A. (2015). Earthquake hypocenters and focal mechanisms in central Oklahoma reveal a complex system of

author Dan McNamara, such information can "aid in adapting building codes to ensure that structures can withstand more damaging earthquakes.[559]

- February 20, 2015 – Scientists with the USGS reported in *Science* about grappling with an unexpected increase in injection-related seismic activity across the middle of North America. In 2014, the number of measured earthquakes with magnitude of 3 or greater in Oklahoma exceeded that in California, and observations increasingly suggested that the effects of fluid injection were not confined to the target formation but instead were communicated, sometimes to greater depths, along pre-existing faults. Making hazard modeling more difficult, "most of these faults are only detected when they are imaged by well-located induced earthquakes." Consequently, predicting and controlling such seismic activity may not be possible, leading to a recommendation that injection projects should be sited away from population centers.[560]

- February 5, 2015 – Citing an association between increased water use and fracking-induced seismic activity, a research scientist at the Geological Survey of Canada offered the quantity of water injected underground as his hypothesis for an observed increase in the frequency and magnitude of earthquake activity in areas near fracking wells. Although the Council of Canadian Academies in 2014 called for more monitoring and data collection, there are only ten monitoring stations in British Columbia, overseeing the operations of thousands of fracking wells, reported the *Vancouver Observer*.[561]

- January 29, 2015 – The industry-funded Alberta Energy Regulator confirmed that the location of an earthquake of magnitude 4.4 near Fox Creek, Alberta, was "consistent with being induced by hydraulic fracturing operations," making it the largest felt earthquake yet believed to be related to fracking. Despite claims from industry that tremors related to deep-level fracking could never reach magnitudes that would allow them to be felt on the surface, Gail Atkinson, who holds the Canada Research Chair in Induced Seismicity Hazards at Western University in Ontario, noted, "With fracking, the magnitudes have been increasing every year."[562]

- January 6, 2015 – Using a specialized program, Miami University researchers analyzed data from multiple seismic stations and determined that a cluster of 77 earthquakes in Poland Township, Ohio, which occurred over the course of a little more than a week, was related temporally and spatially to active hydraulic fracturing operations. When the

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reactivated subsurface strike-slip faulting. *Geophysical Research Letters, 42*(8), 2742–2749. doi: 10.1002/2014GL062730

[559] Koontz, H. (2015, March 6). *Reawakened Oklahoma faults could produce larger future events* [Press release]. Retrieved from http://www.usgs.gov/newsroom/article_pf.asp?ID=4144

[560] McGarr, A., Bekins, B., Burkardt, N., Dewey, J., Earle, P., Ellsworth, W., Ge, S., … Sheehan, A. (2015). Coping with earthquakes induced by fluid injection. *Science, 347*(6224), 830-831. doi: 10.1126/science.aaa0494

[561] Leahy, D. (2015, February 5). Fracking-induced earthquake puts B.C. gas bonanza on shaky ground. *Vancouver Observer.* Retrieved from http://www.vancouverobserver.com/news/fracking-induced-earthquake-puts-bc-gas-bonanza-shaky-ground

[562] Nikiforuk, A. (2015, January 29). Did Alberta just break a fracking earthquake world record? *TheTyee.ca.* Retrieved from http://thetyee.ca/News/2015/01/29/Alberta-Fracking-Earthquake/?utm_source=fb-page-editor-post&utm_medium=fb-page&utm_campaign=fb-01-2015

fracturing operations were shut down, the rate of earthquake activity declined to only 6 events in the next 12 hours and only a single event over approximately the next two months. Among this cluster of seismic activity, an earthquake of magnitude 3.0 ranks as one of the largest earthquakes in the United States to be induced by hydraulic fracturing. The mechanism for these earthquakes appears to be induction of slip along a pre-existing fault or fracture zone. Because "no known fault or historical seismicity had been [previously] identified in the area," regulations prohibiting fracturing within three miles of a known fault would not have been protective.[563, 564]

- December 18, 2014 – In Canada, an investigation by the British Columbia Oil and Gas Commission found that induced seismicity in the Horn River Basin could be attributed both to wastewater disposal and to hydraulic fracturing operations. The Commission recommended mitigation of induced seismicity from wastewater disposal by "reducing injection rates, limiting the increase in [subsurface] reservoir pressure, and locating distal from faults," among other mitigation techniques.[565, 566]

- October 23, 2014 – Researchers from USGS and the Global Seismological Services in Golden, Colorado, linked a 2011 magnitude 5.3 earthquake in Colorado, which damaged the foundations of several homes, to underground disposal of fracking wastewater. The study determined that the earthquake ruptured an 8-10 kilometer-long segment of normal faults—an unexpectedly long length for a magnitude 5.3 earthquake—suggesting that wastewater disposal may have triggered a low stress drop.[567] Lead author Bill Barnhart, a USGS geophysicist, told *Reuters*, "We saw a big increase in seismicity starting in 2001, including magnitude 5 earthquakes, in many locations in the basin, and that coincided with a surge in gas production and injection of wastewater."[568]

- September 23, 2014 – Youngstown State University geologist Ray Beiersdorfer described increased seismic activity in Youngstown, Ohio in an essay that explores how fracking and fracking-related processes are causing "earthquake epidemics" across the United

[563] Skoumal, R. J., Brudzinski, M. R. & Currie, B. S. (2015). Earthquakes induced by hydraulic fracturing in Poland Township, Ohio. *Bulletin of the Seismological Society of America 105*(1). doi: 10.1785/0120140168
[564] Wines, M. (2015, January 10). New research links scores of earthquakes to fracking wells near a fault in Ohio. *The New York Times.* Retrieved from http://www.nytimes.com/2015/01/08/us/new-research-links-scores-of-earthquakes-to-fracking-wells-near-a-fault-in-ohio.html?hp&action=click&pgtype=Homepage&module=first-column-region&region=top-news&WT.nav=top-news&assetType=nyt_now&_r=0
[565] BC Oil & Gas Commission (2014). *Investigation of observed seismicity in the Montney Trend.* Retrieved from http://www.bcogc.ca/node/12291/download
[566] Nikiforuk, A. (2015, January 10). Fracking industry shakes up Northern BC with 231 tremors. *TheTyee.ca.* Retrieved from http://www.thetyee.ca/News/2015/01/10/Fracking_Industry_Shakes_Up_Northern_BC/
[567] Barnhart, W. D., Benz, H.M., Hayes, G.P., Rubinstein, J.L., & Bergman, E. (2014), Seismological and geodetic constraints on the 2011 Mw5.3 Trinidad, Colorado earthquake and induced deformation in the Raton Basin, *J. Geophys. Res. Solid Earth*, *119*, 7923–7933, doi: 10.1002/2014JB011227. Retrieved from http://onlinelibrary.wiley.com/doi/10.1002/2014JB011227/abstract
[568] Zuckerman, L. (2014, October 29). Gas wastewater likely triggered 2011 quake in Colorado: USGS. *Reuters*. Retrieved from http://www.reuters.com/article/2014/10/29/us-usa-earthquake-colorado-idUSKBN0II2NP20141029

States.[569]

- September 15, 2014 – Researchers at the National Energy Technology Laboratory teamed up with researchers from industry and academia to publish data and analysis from a closely watched project that involved field monitoring of the induced fracturing of six horizontal Marcellus Shale gas wells in Greene County, Pennsylvania. Touted in earlier media reports as demonstrating that, during short-term follow-up, fracking chemicals injected into these six wells did not spread to overlying aquifers[570], the study's most notable finding is striking documentation of fractures from three of the six wells extending vertically to reach above an overlying rock layer previously thought to create an impenetrable "frac barrier" (that is, an upper barrier to fracture growth). In one case, a fracture extended vertically 1,900 feet, a surprisingly far distance. No pre-existing fault had been detected at this location, suggesting that small "pre-existing fractures or small-offset (sub-seismic) faults may have focused the energy of hydraulic fractures on certain areas…." Perhaps because of the extremely small sample size and a design focused primarily on monitoring for potential gas and fluid migration, the study's analysis includes no discussion of the seismic relevance of extremely long, vertical induced fractures.[571]

- September 15, 2014 – Scientists from USGS ascribed causality to wastewater injection wells from coal-bed methane production for increases in seismic activity in New Mexico and Colorado and, in particular, for an earthquake that measured magnitude 5.3 in Colorado in 2011—the second largest earthquake to date for which there is clear evidence that the earthquake sequence was induced by fluid injection.[572]

- September 6, 2014 – The Ohio Department of Natural Resources suspended operations at two deep-injection wells for fracking wastewater near Warren in northeastern Ohio after discovering evidence that the operation possibly caused a magnitude 2.1 earthquake. The injection well operator, American Water Management Services, had recently received permission to increase pressures at the site of the wells. In 2012, Governor John Kasich had halted disposal of fracking wastewater surrounding a well site in the same region after a series of earthquakes were tied to a deep-injection well. The company that ran that well has disputed the link. The state placed seismic-monitoring devices in the Warren

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[569] Beiersdorfer, R. (2014, September 23). View: On fracking, earthquakes and Indian Point. *Journal Online.* Retrieved from http://www.lohud.com/story/opinion/contributors/2014/09/23/view-geologist-warns-fracking-ties-earthquakes/16100755/

[570] Begos, K. (2014, July 19). DOE study: Fracking chemicals didn't taint water. *Associated Press*. Retrieved from http://bigstory.ap.org/article/ap-study-finds-fracking-chemicals-didnt-spread

[571] Hammack, R., Harbert, W., Sharma, S., Stewart, B. W., Capo, R. C., Wall, A. J., . . . Veloski, G. (2014). An evaluation of fracture growth and gas/fluid migration as horizontal Marcellus Shale gas wells are hydraulically fractured in Greene County, Pennsylvania. *NETL-TRS-3-2014: EPAct Technical Report Series. US Dept of Energy, National Energy Technology Laboratory*: Pittsburgh PA. Retrieved from http://www.netl.doe.gov/File%20Library/Research/onsite%20research/publications/NETL-TRS-3-2014_Greene-County-Site_20140915_1_1.pdf

[572] Rubinstein, J. L., Ellsworth, W. L., McGarr, A. & Benz, H. M. (2014). The 2001-present induced earthquake sequence in the Raton Basin of Northern New Mexico and Southern Colorado [abstract]. *Bulletin of the Seismological Society of America*. Retrieved from http://www.bssaonline.org/content/104/5/2162.abstract?stoc

area under protocols adopted after the series of earthquakes in nearby Youngstown.[573]

- September 1, 2014 – Explaining the need for increased seismic monitoring, Andrew Beaton, Director of the Alberta Geological Survey, stated that over a long period of time, stresses increase in and around an injection well bore. Seismic movement can be caused if the rate of injection is too fast or if there is a geological feature, such as a fault or fracture in nearby areas. Although Albertans in rural areas have been reporting for years that they can feel tremors under their feet near oil and gas activity, especially around areas of fracking, the Alberta Energy Regulator noted that deep well injections have been shown to create more of an earthquake hazard than hydraulic fracturing. Alberta experienced 819 earthquakes between 1918 and 2009. In comparison, Saskatchewan recorded 13 in the same time period and British Columbia recorded more than 1,200 earthquakes in 2007 alone. There are currently 24 seismic monitors in Alberta, which are tied into other networks, such as those belonging to Environment Canada, University of Calgary, and University of Alberta.[574]

- August 26, 2014 – In a first-of-its-kind lawsuit, a resident of Prague, Oklahoma, sued two energy companies after rocks fell from her chimney and injured her leg during an earthquake of greater than magnitude 5. The lawsuit claims that underground injection of fracking wastewater conducted by New Dominion LLC and Spess Oil Company has caused shifts in fault lines that have resulted in earthquakes.[575]

- July 31, 2014 – William Ellsworth, a research geophysicist at the USGS Earthquake Science Center, reported that USGS is developing a hazard model that takes induced earthquakes into account. In addition, residents of Oklahoma, where a sharp spike in earthquake activity has been noted over the past decade, are showing an increased interest in obtaining earthquake insurance.[576]

- July 3, 2014 – Using data from the Oklahoma Corporation Commission, a team of researchers led by Cornell University geophysicist Katie Keranen found that a steep rise in earthquakes in Oklahoma can be explained by fluid migration from wastewater disposal wells. Moreover, injected fluids in high volume wells triggered earthquakes over 30 kilometers (over 18 miles) away. All of the wells analyzed were operated in compliance with existing regulations. Similar mechanisms may function in other states with high volumes of underground injection of wastewater from unconventional oil and

[573] Smyth, J. C. (2014, September 6). Ohio halts injections at two wells for fracking wastewater after quake. *Associated Press*. Retrieved from http://www.dispatch.com/content/stories/local/2014/09/06/ohio-halts-2-wells-for-fracking-wastewater-after-quake.html
[574] Maclean, R. (2014, September 1). Earthquake hazard linked with deep well injection in Alberta: Deep well disposal of oilfield waste over time leads to increased earthquake risk. *CBC News*. Retrieved from http://www.cbc.ca/news/canada/calgary/earthquake-hazard-linked-with-deep-well-injection-in-alberta-1.2751963
[575] Rangel, L. (2014, August 26). Prague resident files lawsuit against two Okla. energy companies following earthquake injury. *Newschannel 4 (kfor.com)*. Retrieved from http://kfor.com/2014/08/26/prague-resident-files-lawsuit-against-two-okla-energy-companies-following-earthquake-injury/
[576] Eaton, J. (2014, July 31). Oklahoma grapples with earthquake spike—and evidence of industry's role: Spike in seismic activity is linked with oil and gas wastewater disposal. *National Geographic*. Retrieved from http://news.nationalgeographic.com/energy/2014/07/140731-oklahoma-earthquake-spike-wastewater-injection/

gas production.[577] Reporting on the study and the increase in earthquakes across the United States and the link to fracking and wastewater disposal, the *Associated Press* noted that some states, including Ohio, Oklahoma, and California, have introduced new rules compelling drillers to measure the volumes and pressures of their injection wells as well as to monitor seismicity during fracking operations.[578]

- July 1, 2014 – Seismologists linked the emergence of a giant sinkhole that formed in August 2012 near Bayou Corne in southeast Louisiana to tremors (earthquakes) caused by high-pressure pulses of either natural gas or water charged with natural gas. The surges of natural gas that caused the explosive tremors (earthquakes) may have weakened an adjacent salt cavern and caused its collapse. Alternatively, part of the salt cavern may have collapsed, causing a nearby gas pocket to give off surges of gas, later followed by the complete collapse of the salt cavern. These findings help illuminate the role of pressurized fluids in triggering seismic events.[579]

- June 24, 2014 – Following two earthquakes within a one-month period, the Colorado Oil and Gas Conservation Commission directed High Sierra Water Services to stop disposing wastewater into one of its Weld County injection wells. Monitoring by a team of seismologists from the University of Colorado had picked up evidence of continuing low-level seismic activity near the injection site, including a magnitude 2.6 event less than a month following a magnitude 3.4 earthquake that shook the Greeley area on May 31, 2014.[580]

- May 2, 2014 – The USGS and Oklahoma Geological Survey (OGS) jointly issued an official earthquake warning for Oklahoma, pointing out that the number of earthquakes in the state has risen 50 percent since just October—when the two agencies had issued a prior warning. The advisory stated that this dramatic increase in the frequency of small earthquakes "significantly increases the chance for a damaging quake in central Oklahoma." Injection wells used for the disposal of liquid fracking waste have been implicated as the presumptive cause of the earthquake swarm. According to the OGS, about 80 percent of the state of Oklahoma is closer than ten miles from an injection well.[581] Since the joint earthquake advisory was released in May, the number of

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[577] Keranen, K. M., Weingarten, M., Abers, G. A., Bekins, B. A., & Ge, S. (2014). Sharp increase in central Oklahoma seismicity since 2008 induced by massive wastewater injection. *Science, 345*(6195), 448-451. doi: 10.1126/science.1255802

[578] Schmall, E. & Jouzapavicius, J. (2014, July 14). States with fracking see surge in earthquake activity. *Associated Press*. Retrieved from http://www.huffingtonpost.com/2014/07/14/fracking-earthquake_n_5585892.html

[579] Nayak, A. & Dreger, D. S. (2014). Moment tensor inversion of seismic events associated with the sinkhole at Napoleonville Salt Dome, Louisiana. *Bulletin of Seismological Society of America 104(4),* 1763-1776. doi: 10.1785/0120130260

[580] Tomasic, J. (2014, June 24). Colorado drilling regulators halt injection-well activity in reaction to Greeley quake. *Colorado Independent*. Retrieved from http://www.coloradoindependent.com/147934/colorado-drilling-regulators-halt-injection-well-activity-in-reaction-to-greeley-quake (see also Baker, B. (2014, June 24). Colorado regulators halt fracking wastewater injection operation after earthquake strikes area for second time in a month. *Ecowatch*. Retrieved from http://ecowatch.com/2014/06/24/colorado-wastewater-injection-earthquake/)

[581] Geological Survey Joint Statement. (2014, May 2). Record number of Oklahoma tremors raises possibility of damaging earthquakes. United States Geological Survey. Retrieved from http://earthquake.usgs.gov/regional/ceus/products/newsrelease_05022014.php

earthquakes in Oklahoma has continued to rise. During the first four months of 2014, Oklahoma had experienced 109 earthquakes of magnitude 3 or higher on the Richter scale. By mid-June, the number of earthquakes had topped 200, exceeding the frequency of earthquakes in California.[582]

- May 2, 2014 – At the annual meeting of the Seismological Society of America, leading geologists warned that the risks and impacts of earthquakes from fracking and injection wells are even more significant than previously thought, pointing out that such earthquakes could occur tens of miles away from wells themselves, including quakes greater than magnitude 5.0. Justin Rubinstein, a research geophysicist at the USGS said, "This demonstrates there is a significant hazard. We need to address ongoing seismicity."[583] Seismologist Gail Atkinson reported, "We don't know how to evaluate the likelihood that a [fracking or wastewater] operation will be a seismic source in advance."[584]

- April 11, 2014 – State geologists reported a link between fracking and a spate of earthquakes in Ohio, prompting the Ohio Department of Natural Resources to place a moratorium on drilling in certain areas and to require greater seismic monitoring.[585]

- April 3, 2014 – Researchers linked earthquakes in Mexico to fracking in the Eagle Ford Shale, which extends beneath both southern Texas and northern Mexico. They also noted a statistical correlation between seismic activity and fracking, particularly in the border state of Nuevo Leon, which registered at least 31 quakes between magnitude 3.1 and 4.3.[586]

- April 2014 – Researchers from the University of Alberta and the Alberta Geological Survey published a study in the *Journal of Geophysical Research* that found wastewater injection in Alberta is highly correlated with spikes of seismic activity between October 2006 and March 2012.[587] On November 13, 2014, *CBC News* reported on a more recent

[582] Branson-Potts, H. (2014, June 17). Oklahoma coming to terms with unprecedented surge in earthquakes. *Los Angeles Times*. Retrieved from http://www.latimes.com/nation/la-na-oklahoma-earthquakes-20140618-story.html#page=1
[583] Walsh, B. (2014, May 1). The seismic link between fracking and earthquakes. *Time*. Retrieved June 9, 2014, from http://time.com/84225/fracking-and-earthquake-link/
[584] Kiger, P. J. (2014, May 2). Scientists warn of quake risk from fracking operations. *National Geographic*. Retrieved from http://news.nationalgeographic.com/news/energy/2014/05/140502-scientists-warn-of-quake-risk-from-fracking-operations/
[585] Dave, P. (2014, April 12). Ohio finds link between fracking and sudden burst of earthquakes. *Los Angeles Times*. Retrieved from http://www.latimes.com/nation/nationnow/la-na-nn-ohio-finds-link-fracking-earthquakes-20140411-story.html#axzz2yrnpHW1h
[586] Godoy, E. (2014, April 3). Fracking, seismic activity grow hand in hand in Mexico. *Inter Press Service*. Retrieved from http://www.ipsnews.net/2014/04/fracking-seismic-activity-grow-hand-hand-mexico/
[587] Schultz, R., Stern, V. & Gu, Y. J. (2014). An investigation of seismicity clustered near the Cordel Field, west central Alberta, and its relation to a nearby disposal well. *Journal of Geophysical Research: Solid Earth, 119,* 3410–3423. doi: 10.1002/2013JB010836

increase in earthquakes, which may also be linked to injection wells.[588]

- March 7, 2014 – USGS researchers published a study confirming that Oklahoma's damaging magnitude 5.7 earthquake in 2011 was caused by fracking wastewater injection.[589] One of the authors of the study, seismologist Elizabeth Cochran, noted, "Even if wastewater injection only directly affects a low-hazard fault, those smaller events could trigger an event on a larger fault nearby."[590]

- January 30, 2014 – A USGS research team linked the rise in earthquakes in Colorado to fracking wastewater injection wells and announced that a study will be published in six to nine months.[591]

- December 12, 2013 – The *New York Times* detailed the growing link between fracking wastewater injection wells and earthquakes, as well as between fracking itself and earthquakes, with a focus on Oklahoma and a recent magnitude 4.5 earthquake there. As the *New York Times* noted, "Oklahoma has never been known as earthquake country, with a yearly average of about 50 tremors, almost all of them minor. But in the past three years, the state has had thousands of quakes. This year has been the most active, with more than 2,600 so far, including 87 last week…. State officials say they are concerned, and residents accustomed to tornadoes and hail are now talking about buying earthquake insurance."[592]

- November 19, 2013 – *Reuters* reported that a series of Oklahoma earthquakes in September of 2013 damaged several homes, and that more scientists in a number of states are concerned about earthquakes related to oil and gas development. Seismologist Austin Holland with the University of Oklahoma said, "This is a dramatic new rate of seismicity."[593]

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588 Trynacity, K., & Siekierska, A. (2014, November 13). Fracking linked to Alberta earthquakes, study indicates. *CBC News*. Retrieved from http://www.cbc.ca/news/canada/edmonton/fracking-linked-to-alberta-earthquakes-study-indicates-1.2829484

589 Sumy, D. F., Cochran, E. S., Keranen, K. M., Wei, M., & Abers, G. A. (2013). Observations of static Coulomb stress triggering of the November 2011 M5.7 Oklahoma earthquake sequence [Abstract]. *Journal of Geophysical Research: Solid Earth, 119*(3), 1904-1923. doi: 10.1002/2013JB010612

590 Oskin, B. (2014, March 07). Wastewater injection triggered Oklahoma's earthquake cascade. *Live Science*. Retrieved from http://www.livescience.com/43953-wastewater-injection-earthquake-triggering.html

591 McClurg, L. (2014, January 30). Earthquakes in southern Colorado linked to oil and gas production. *Colorado Public Radio*. Retrieved from http://www.cpr.org/news/story/earthquakes-southern-colorado-linked-oil-and-gas-production#sthash.UVvw0JWe.UQwWtYJS.dpuf

592 Fountain, H. (2013, December 12). Experts eye oil and gas industry as quakes shake Oklahoma. *The New York Times*. Retrieved from http://www.nytimes.com/2013/12/13/science/earth/as-quakes-shake-oklahoma-scientists-eye-oil-and-gas-industry.html

593 Gillam, C. (2013, November 19). In Oklahoma, water, fracking - and a swarm of quakes. *Reuters*. Retrieved from http://www.reuters.com/article/2013/11/19/us-usa-earthquakes-fracking-oklahoma-idUSBRE9AI12W20131119

- July 19, 2013 – A study from the Lamont-Doherty Earth Observatory linked 109 earthquakes in Youngstown, Ohio to fracking wastewater disposal.[594, 595]

- July 11, 2013 – A study in *Science* by Columbia University's Lamont-Doherty Earth Observatory showed that deep-well injection of fracking waste can stress geological faults in ways that make them vulnerable to slipping. The research shows that distant natural earthquakes triggered swarms of smaller earthquakes on critically stressed faults. The researchers wrote, "The fluids [in wastewater injection wells] are driving the faults to their tipping point…. Areas with suspected anthropogenic earthquakes are more susceptible to earthquake-triggering from natural transient stresses generated by the seismic waves of large remote earthquakes."[596]

- April 2013 – A group of British researchers stated that hydraulic fracturing itself was the likely cause of at least three earthquakes powerful enough to be felt by human beings at the surface. The researchers proposed that increases in the fluid pressure in fault zones were the causal mechanism for these three known instances of "felt seismicity" in the United States, Canada, and the United Kingdom. The largest of these earthquakes was a magnitude 3.8 in the Horn River Basin, Canada.[597]

- March 26, 2013 – Scientists from the University of Oklahoma, Columbia University and USGS linked a 2011 swarm of earthquakes in Oklahoma to fracking waste disposal in that state.[598] This included a magnitude 5.7 earthquake—possibly the largest ever triggered by wastewater injection—that injured two people, destroyed 14 homes, and was felt across 17 states.[599] The research team concluded in a paper in the journal *Geology* that their data called into question the previously predicted maximum size of injection-induced earthquakes.[600, 601]

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594 Kim, W. (2013). Induced seismicity associated with fluid injection into a deep well in Youngstown, Ohio. *Journal of Geophysical Research: Solid Earth, 118*(7), 3506-3518. doi: 10.1002/jgrb.50247

595 Chameides, B. (2013, September 5). Fracking waste wells linked to Ohio earthquakes. *Scientific American*. Retrieved from http://www.scientificamerican.com/article/fracking-waste-wells-linked-to-ohio-earthquakes/

596 Begley, S. (2013, July 11). Study raises new concern about earthquakes and fracking fluids. *Reuters*. Retrieved from http://www.reuters.com/article/2013/07/11/us-science-fracking-earthquakes-idUSBRE96A0TZ20130711

597 Davies, R., Foulger, G., Bindley, A., & Styles, P. (2013). Induced seismicity and hydraulic fracturing for the recovery of hydrocarbons. *Marine and Petroleum Geology, 45*, 171-185. doi: 10.1016/j.marpetgeo.2013.03.016

598 Drajem, M., & Efstathiou, J., Jr. (2013, March 26). Quake tied to oil-drilling waste adds pressure for rules. *Bloomberg*. Retrieved from http://www.bloomberg.com/news/2013-03-26/oklahoma-earthquake-in-2011-tied-to-wastewater-wells-in-fracking.html

599 Behar, M. (2013, March/April). Fracking's latest scandal? Earthquake swarms. *Mother Jones*. Retrieved from http://www.motherjones.com/environment/2013/03/does-fracking-cause-earthquakes-wastewater-dewatering?page=1

600 Keranen, K. M., Savage, H. M., Abers, G. A., & Cochran, E.S. (2013). Potentially induced earthquakes in Oklahoma, USA: Links between wastewater injection and the 2011 Mw 5.7 earthquake sequence. *Geology*. doi: 10.1130/G34045.1

601 Diep, F. (2013, March 28). Study: wastewater injection caused Oklahoma's largest-ever earthquake. *Popular Science*. Retrieved from http://www.popsci.com/science/article/2013-03/largest-earthquake-ever-linked-lightly-regulated-wastewater-wells

- December 14, 2012 – At a 2012 American Geophysical Union meeting, scientists presented data and concluded that some U.S. states, including Oklahoma, Texas and Colorado, have experienced a significant rise in seismic activity coinciding with a boom in gas drilling, fracking and wastewater disposal. Scientists further found that Oklahoma has seen a significant increase in earthquakes linked to wastewater injection, that a 5.3 earthquake in New Mexico was linked to wastewater injection, and that earthquakes were increasingly common within two miles of injection wells in the Barnett Shale region of Texas. Art McGarr, a researcher at the USGS Earthquake Science Center, concluded that, "The future probably holds a lot more in induced earthquakes as the gas boom expands."[602]

- November 30, 2012, January 11, 2012, December 22, 2009 – In three different sets of comments on proposed fracking guidelines and regulations, citing scientific reports linking oil and gas infrastructure to seismic activity, the New York City Department of Environmental Protection (NYC DEP) raised serious concerns about the impacts of potential seismic activity from fracking-related activities on New York City's water supply infrastructure.[603, 604, 605] The NYC DEP has consistently raised concerns that seismic activity surrounding New York City's aquifers and watershed infrastructure could threaten the city's drinking water supply by triggering microseismic events and small induced earthquakes that, in turn, could threaten the integrity of the aging, 100-mile-long aqueducts that carry drinking water from the Catskill Mountains into the New York City metropolitan area. The agency expressed specific concerns about the ability of hydraulic fracturing fluids to migrate underground and to intercept and reactivate faults miles away.

- September 6, 2012 – The British Columbia Oil and Gas Commission determined that fracking itself causes earthquakes, pointing to the results of a probe into 38 seismic events near fracking operations in the Horn River Basin. The report noted that no quakes had been recorded in the area prior to April 2009, before fracking began. The report recommended that the link between fracking and seismic activity be further examined.[606]

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602 Leber, J. (2012, December 14). Studies link earthquakes to wastewater from fracking. *MIT Technology Review*. Retrieved from http://www.technologyreview.com/news/508151/studies-link-earthquakes-to-wastewater-from-fracking/

603 New York City Department of Environmental Protection. (2009, December 22). *New York City comments on: Draft supplemental generic environmental impact statement on the oil, gas and solution mining regulatory program - Well permit issuance for horizontal drilling and high-volume hydraulic fracturing to develop the Marcellus Shale and other low-permeability gas reservoirs* (Rep.). Retrieved from http://www.nyc.gov/html/dep/pdf/natural_gas_drilling/nycdep_comments_final_12-22-09.pdf

604 New York City Department of Environmental Protection. (2012, January 11). *Comments on the revised draft supplemental generic environmental impact statement*. (Rep.). Retrieved from http://www.nyc.gov/html/dep/pdf/natural_gas_drilling/nycdep_comments_on_rdsgeis_for_hvhf_20120111.pdf

605 New York City Department of Environmental Protection. (2012, November 30). *Comments on the revised high-volume hydraulic fracturing regulations* (Rep.). Retrieved from http://www.nyc.gov/html/dep/pdf/natural_gas_drilling/revised_high_volume_hydraulic_fracturing_regulations_comments_letter_010713.pdf

606 The Canadian Press. (2012, September 6). Fracking causes minor earthquakes, B.C. regulator says. *CBC News*. Retrieved from http://www.cbc.ca/news/canada/british-columbia/fracking-causes-minor-earthquakes-b-c-regulator-says-1.1209063

- March 29, 2012 – The USGS found that between 2001 and 2011, there was a six-fold increase in earthquakes greater than magnitude 3.0 in the middle of the United States that "are almost certainly manmade." The agency further reported that the increase appears to be linked to oil and gas production and deep injection of drilling wastewater.[607, 608]

- July 31, 2011 – Numerous earthquakes in Arkansas motivated the Arkansas Oil and Gas Commission to shut down a disposal well and enact a permanent moratorium on future disposal wells in a nearly 1,200 square-mile area of the Fayetteville Shale.[609]

- March 10, 2010 – In Texas, a 2008-2009 swarm of earthquakes in the Dallas-Fort Worth area was linked to produced water disposal wells.[610]

- June 12, 2009 – *The Wall Street Journal* reported that earthquakes shook Cleburne, Texas, a small town at the epicenter of fracking activity. More earthquakes were detected during that period of fracking activity than in the previous 30 years combined.[611]

Abandoned and active oil and natural gas wells as pathways for gas and fluid migration

An estimated 2.6 million oil and gas wells across the United States are no longer in production. The location and status of the vast majority are not recorded in state databases, and most remain unplugged. Whether plugged or unplugged, abandoned wells are a significant source of methane leakage into the atmosphere and, based on findings from New York and Pennsylvania, may exceed cumulative total leakage from oil and gas wells currently in production. No state or federal agency routinely monitors methane leakage from abandoned wells. Abandoned wells also serve as underground pathways for fluid migration, heightening risks of groundwater contamination. Fluid can migrate upward through vertical channels when fractures from new drilling and fracking operations intersect with old wells. Industry experts, consultants, and government agencies including the U.S. Environmental Protection Agency (EPA), the U.S. Government Accountability Office (GAO), Texas Department of Agriculture, New York State

[607] Ellsworth, W. (2011, April 18). Are seismicity rate changes in the midcontinent natural or manmade? Retrieved from http://www2.seismosoc.org/FMPro?-db=Abstract_Submission_12&-sortfield=PresDay&-sortorder=ascending&-sortfield=Special+Session+Name+Calc&-sortorder=ascending&-sortfield=PresTimeSort&-sortorder=ascending&-op=gt&PresStatus=0&-lop=and&-token.1=ShowSession&-token.2=ShowHeading&-recid=224&-format=%2Fmeetings%2F2012%2Fabstracts%2Fsessionabstractdetail.html&-lay=MtgList&-find

[608] Soraghan, M. (2012, March 29). 'Remarkable' spate of man-made quakes linked to drilling, USGS team says. *E&E Publishing, LLC*. Retrieved from http://www.eenews.net/stories/1059962190

[609] Zilk, C. (2011, July 31). Permanent disposal-well moratorium issued. *Arkansas Online*. Retrieved from http://www.arkansasonline.com/news/2011/jul/31/permanent-disposal-well-moratorium-issued-20110731/

[610] Frohlich, C., Hayward, C., Stump, B., & Potter, E. (2011). The Dallas-Fort Worth Earthquake Sequence: October 2008 through May 2009. *Bulletin of the Seismological Society of America*, *101*(1), 327-340. doi: 10.1785/0120100131

[611] Casselman, B. (2009, June 12). Temblors rattle Texas town. *Wall Street Journal*. Retrieved from http://online.wsj.com/news/articles/SB124476331270108225

Department of Environmental Conservation (NYS DEC), Pennsylvania Department of Environmental Protection (PA DEP), Illinois Environmental Protection Agency, and the British Columbia Oil and Gas Commission have all warned about problems with abandoned wells due to the potential for pressurized fluids and gases to migrate through inactive and, in some cases, active wells.

- Dec 26, 2017 – In 1965, a blowout at a gas well in northeastern Netherlands caused the formation of quicksand, which swallowed up an entire drill rig. Eventually, the area was turned into a park. More than 50 years later, a team of researchers discovered that the site is still leaking methane. They found in the groundwater high levels of methane with an isotopic composition that matched that of the gas reservoir. An analysis of groundwater flow conditions showed that this methane is not a remnant of the blowout but the result of ongoing leakage. "Combined, the data reveal the long-term impact that underground gas well blowouts may have on groundwater chemistry, as well as the important role of anaerobic oxidation in controlling the fate of dissolved methane."[612, 613]

- June 28, 2017 – *The Tyee* made public the results of an unreleased 2016 report by the Alberta Energy Regulator (AER) showing that 36 of 335 abandoned oil and gas wells that are located close to occupied buildings in urban areas of Alberta are leaking methane. Six abandoned wells were leaking at levels (10,000 ppm) that pose explosion risks and are considered life-threatening. (Natural background level is about 1.9 ppm.) Based on these findings, the report also estimated that 17,000 of 170,000 abandoned wells in rural Alberta were likely also leaking. The author of the unreleased report said in an interview with *The Tyee* that AER, a corporation that functions in part as a regulatory agency, does not have the capacity to evaluate the potential threat to public health and safety. "The expertise to assess the health risk of abandoned wells really doesn't exist in house."[614, 615]

- March 27, 2017 – In an experimental study, Canadian researchers injected methane gas into a shallow sand aquifer over a 72-day period and monitored methane migration for eight months. After 72 days, they found that half of the methane had vented into the atmosphere and half remained in the groundwater, traveling laterally a greater distance than expected and degrading at a rate less than expected. "Our findings demonstrate that

[612] Schout, G., Hartog, N., Hassanizadeh, S. M., & Griffioen, J. (2018). Impact of an historic underground gas well blowout on the current methane chemistry in a shallow groundwater system. *Proceedings of the National Academy of Sciences*, *115*(2), 296-301. Advance online publication. doi: 10.1073/pnas.1711472115
[613] Yirka, B. (2017, December 29). Methane still leaking from the ground at site of gas explosion decades ago. *Phys.org.* Retrieved from https://phys.org/news/2017-12-methane-leaking-ground-site-gas.html
[614] Nikiforuk, A. (2017, June 28). Energy industry legacy: Hundreds of abandoned wells leaking methane in Alberta communities. *The Tyee.* Retrieved from https://thetyee.ca/News/2017/06/28/Energy-Industry-Legacy/
[615] Nikiforuk, A. (2017, July 4). Alberta failing on risk from leaking oil and gas wells, says expert. *The Tyee.* Retrieved from https://thetyee.ca/News/2017/07/04/Alberta-Failing-Leaking-Oil-Gas-Wells-Risk/

even small-volume releases of methane gas can cause extensive and persistent free phase and solute plumes."[616, 617]

- December 21, 2016 – The *Texas Tribune* investigated abandoned oil wells in Texas where the Texas Railroad Commission, which is charged with regulating the oil and gas industry, has tracked and mapped 6,628 unplugged, orphaned wells. The commission is struggling with a ballooning inventory of inactive, leaking wells and decreasing clean-up funds to deal with them. The most recent oil boom, involving horizontal drilling with fracking, added to the problem as drillers cut corners in the rush to bring oil to market. "Just drill the well as fast as possible, because they were under such pressure to get cash flow going," according to a geoscientist interviewed for the story who had recently retired as a groundwater advisor for the Railroad Commission.[618]

- November 14, 2016 – Methane emissions from abandoned wells vary widely, with a few high emitters responsible for a disproportionately large share of the problem. Using new field measurement and data mining techniques, a Stanford University-led team investigated gas leaks at 88 inactive wells in Pennsylvania in an attempt to identify the characteristics of these "super-emitters." Their results showed that unplugged gas wells and wells located in coal areas had the highest methane flow rates. Well plugging does not always reduce methane emission, especially when the wells are vented. In many areas with extensive coal layers, decommissioning requirements for wells included mandatory venting. Using comprehensive databases, the team also estimated the number of abandoned wells in Pennsylvania to be between 470,000 and 750,000, considerably more than previous estimates of 300,000 to 500,000. The research team calculated that, all together, Pennsylvania's abandoned wells contribute 5-8 percent of the state's annual greenhouse gas emissions.[619, 620]

- June 20, 2016 – Pennsylvania's attorney general began reviewing regulations requiring drillers to document abandoned oil and gas wells within 1,000 feet of a new fracking site. According to a *Bloomberg* investigation, "This puts Pennsylvania among states such as California, Texas, Ohio, Wyoming and Colorado confronting the environmentally catastrophic legacy of booms as fracking and home development expand over former drilling sites. As the number of fracked wells increases, so does the chance they might

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[616] Cahill, A. G., Steelman, C. M., Forde, O., Kuloyo, O., Ruff, S. E., Mayer, B., … Parker, B. L. (2017). Mobility and persistence of methane in groundwater in a controlled-release field experiment. *Nature Geoscience, 10,* 289–294. doi: 10.1038/ngeo2919

[617] Nikiforuk, A. (2017, April 11). Methane leaks from energy wells affects groundwater, travels great distances, study confirms. *The Tyee.* Retrieved from https://thetyee.ca/News/2017/04/11/Methane-Leaks-from-Energy-Wells-Affects-Groundwater/

[618] Malewitz, J. (2016, December 21). Abandoned Texas oil wells seen as "ticking time bombs" of contamination. *Texas Tribune.* Retrieved from https://www.texastribune.org/2016/12/21/texas-abandoned-oil-wells-seen-ticking-time-bombs-/

[619] Kang, M., Christian, S., Celia, M. A., Mauzerall, D. L., Bill, M., Miller, A. R., … Jackson, R. B. (2016). Identification and characterization of high methane-emitting abandoned oil and gas wells. *Proceedings of the National Academy of Sciences, 113*(48), 13636-13641. doi: 10.1073/pnas.1605913113

[620] Than, K. (2016, November 14). Stanford study of abandoned oil and gas wells reveals new ways of identifying and fixing the worst methane emitters. *Stanford News.* Retrieved from https://news.stanford.edu/2016/11/14/study-abandoned-oil-gas-wells-reveals-new-ways-fixing-worst-methane-emitters/

interact with lost wells." As noted by *Bloomberg*, state databases document only about 10 percent of the nation's 2.6 million abandoned oil and gas wells; the whereabouts of the vast majority are unknown. Current efforts in Pennsylvania to increase documentation on the location and status of inactive wells rely on "citizen scientists" equipped with GPS and methane sniffers, as well as home and farm-owners living on top of abandoned wells. Over a period of three decades, PA DEP has located and plugged only about 3,000 abandoned wells.[621]

- May 30, 2016 – New developments of houses, schools, and shopping centers are being built over abandoned oil and gas wells, according to a report by Wyoming Public Media. In most states there is no requirement for homeowners to be notified about abandoned wells on their properties, and these wells are not systematically monitored for leaks, nor are their locations well mapped. A builder who worked in the oil and gas industry for decades and suffered cardiac arrest when methane from an abandoned well he was inadvertently working atop exploded, said that there were "no signs" that a well was there.[622]

- January 26, 2016 – Researchers tested soil methane levels at 102 United Kingdom decommissioned oil and gas wells between 8 and 79 years old. Thirty percent of the wells had methane at the soil surface that was significantly higher than their control samples in nearby fields. Thirty-nine percent of well sites had significantly lower surface soil methane than their respective controls. Researchers suggested several explanations for the latter results, including replaced soils.[623]

- October 20, 2015 – Abandoned oil and gas wells near fracking sites can be conduits for methane escape that is not currently being measured, according to University of Vermont researchers. Fractures in the surrounding rock may connect to existing unused oil and gas wells in the area during fracking processes, thus providing a pathway for methane to migrate to the surface. The study used a mathematical model based on the large part of southern New York State underlain by the Marcellus Shale, incorporating "the depth of a new fracturing well, the vertical growth of induced fractures, and the depths and locations of existing nearby wells." The researchers concluded the probability that new fracking-induced fractures would connect to a pre-existing well to be .03 percent to 3 percent. Density of nearby abandoned wells was the largest factor, and researchers pointed out the continuing problem of undocumented abandoned wells.[624] As noted in an accompanying press release, probabilities are likely much higher: "Industry-sponsored information made

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[621] Oldham, J. (2016, June 20). In the birthplace of U.S. oil, methane gas is leaking everywhere. *Bloomberg.* Retrieved from http://www.bloomberg.com/news/articles/2016-06-20/in-the-birthplace-of-u-s-oil-methane-gas-is-leaking-everywhere
[622] Editor. (2016, May 30). Danger below? New properties hide abandoned oil and gas wells. *Wyoming Public Media.* Retrieved from http://wyomingpublicmedia.org/post/hidden-abandoned-dangerous-old-gas-and-oil-wells-neighborhoods
[623] Boothroyd, I. M., Almond, S., Qassim, S. M., Worrall, F., & Davies, R. J. (2016). Fugitive emissions of methane from abandoned, decommissioned oil and gas wells. *Science of the Total Environment*, *547*, 461-469. doi: 10.1016/j.scitotenv.2015.12.096
[624] Montague, J. A. & Pinder, J. F. (2015). Potential of hydraulically induced fractures to communicate with existing wellbores. *Water Resources Research*, *51*, 8303–8315. doi: 10.1002/2014WR016771

public since the paper was published vastly increased assumptions about the area impacted by a set of six to eight fracking wells known as a well pad – to two square miles – increasing the probabilities cited in the paper by a factor of 10 or more."[625]

- July 9, 2015 – As part of an extensive, peer-reviewed assessment of fracking in California, the California Council on Science and Technology identified leakage through failed, inactive wells as a known mechanism for fracking-related water contamination in other states, including Texas and Ohio, and said that it is not known whether abandoned wells in California likewise function as conduits for groundwater contamination and gas leakage. In California, there are more inactive than active wells. Of the state's nearly one-quarter million oil and gas wells, more than half (116,000) have been plugged and abandoned, while another 1,800 inactive wells are "buried" with only an approximate location known. The locations of another 338 old wells are entirely unknown. California also has 110 orphaned wells, that is, abandoned wells with no owners. Most of California's abandoned wells (53 percent) are located in Kern County.[626]

- May 11, 2015 – *CBC News* reported that falling gas and oil prices have prompted many smaller companies to abandon their operations in Alberta, Canada, leaving the provincial government to close down and dismantle their wells. In the past year alone, the number of orphaned wells in Alberta increased from 162 to 702. At the current rate of work, deconstructing the inventory of wells abandoned just in the past year alone will be a 20-year task.[627]

- April 27, 2015 – In a peer-reviewed study, researchers with the U.S. Fish and Wildlife Service documented 5,002 wells located on National Wildlife Refuge System units, in addition to 1,339 miles of pipeline. Almost half of the wells were inactive, while one-third were active and the remainder either plugged and abandoned or with status unknown. Highlighting the impacts of leaks, spills, and routine operation and maintenance on wildlife conservation efforts, the authors called for regular on-site ecological assessments, improved efforts to plug inactive wells and restore inactive well sites, and a "consolidated and robust regulatory framework" to protect the public's interests.[628]

- March 24, 2015 – Analyzing data from 42 abandoned oil and gas wells in western Pennsylvania, a Princeton and Stanford team documented a wide range of leakage potentials. As a group, gas wells have higher permeability than oil wells. Among gas wells, methane flow rates are positively correlated with permeability. Subterranean

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[625] Newswise. (2015, October 20). Dirty pipeline: Methane from fracking sites can flow to abandoned wells, new study shows. *Newswise.* Retrieved from http://www.newswise.com/articles/view/641581/

[626] Stringfellow, W. T., Cooley H., Varadharajan, C., Heberger, M., Reagan, M. T., Domen, J.K., . . . Houseworth, J. E. (2015, July 9). Volume II, Chapter 2: Impacts of well stimulation on water resources. In: *An Independent Scientific Assessment of Well Stimulation in California.* California Council on Science and Technology, Sacramento, CA. Retrieved from http://ccst.us/publications/2015/vol-II-chapter-2.pdf

[627] Johnson, T. (2015, May 11). Alberta sees huge spike in abandoned oil and gas wells. *CBC News.* Retrieved from http://www.cbc.ca/news/canada/calgary/alberta-sees-huge-spike-in-abandoned-oil-and-gas-wells-1.3032434

[628] Ramirez Jr., P. & Mosley, S. B. (2015). Oil and gas wells and pipelines on U.S. wildlife refuges: Challenges for managers. *PLoS ONE, 10*(4). doi: 10.1371/journal.pone.0124085

temperatures and temperatures, along with well depth, are all variables that can influence leakage potentials of abandoned wells. The leakage potential of wells drilled prior to 1960 is moderate to high, and plugged wells, as well as unplugged wells, can leak. The authors note that cement plugs are imperfect barriers that can develop defects that allow fluids to flow through gaps between the plug and surrounding hole, through pores or fissures within the plug itself, or directly through cracks in the well casing.[629]

- December 8, 2014 – A Princeton University team found that abandoned oil and gas wells in Pennsylvania, left over from prior decades of conventional drilling, leak significantly more methane than previously thought. Between 300,000 and 500,000 abandoned oil and gas wells are located in Pennsylvania, and many go unchecked and unmonitored for leaks. Nearly three-quarters are unplugged. Based on direct measurements of methane flow from 19 such wells, most of which were a half century old or older, the researchers estimated that the methane leaks from abandoned wells alone could account for between 4 and 7 percent of human-caused methane emissions in the state. Based on these measurements of positive methane flow from decades-old wells, the authors concluded that cumulative emissions from these abandoned wells "may be significantly larger than the cumulative leakage associated with oil and gas production, which has a shorter lifetime of operation." Further, methane flow rates from plugged wells measured in this study were not consistently lower than unplugged wells and indeed were sometimes higher, even though wells are plugged for the precise purpose of limiting the escape of gases. The authors noted that an estimated three million abandoned oil and gas wells are scattered across the United States and likely represent "the second largest potential contribution to total US methane emissions above US Environmental Protection Agency estimates." In the United States, no regulatory requirements for monitoring methane leaks from abandoned wells exist.[630, 631]

- December 1, 2013 – An analysis of reports from the NYS DEC found that three-quarters of the state's abandoned oil and gas wells were never plugged. New York State has approximately 48,000 such wells; many of their locations remain unknown.[632]

- Aug. 4, 2011 – A report from the EPA to Congress in 1987—and discovered by the *New York Times*—concluded that abandoned natural gas wells may have served as a pathway for hydraulic fracturing fluids to migrate underground from a shale gas well to a water well in West Virginia. In noting that the water well was polluted due to hydraulic fracturing and that such contamination was "illustrative" of contamination from oil and

[629] Kang, M., Baik, E., Miller, A. R., Bandilla, K. W., & Celia, M. A. (2015). Effective permeabilities of abandoned oil and gas wells: analysis of data from Pennsylvania. *Environmental Science & Technology, 49*(7). doi: 10.1021/acs.est.5b00132
[630] Kang, M., Kanno, C. M., Reid, M. C., Zhang, X., Mauzerall, D. L., Celia, M. A., . . . Onstott, T. C. (2014, December 8). Direct measurements of methane emissions from abandoned oil and gas wells in Pennsylvania. *Proceedings of the Natural Academy of Sciences*. Advance online publication. doi: 10.1073/pnas.1408315111
[631] Magill, B. (2014, June 19). Derelict oil wells may be major methane emitters. *Climate Central.* Retrieved from http://www.climatecentral.org/news/abandoned-oil-wells-methane-emissions-17575
[632] Bishop, R. E. (2014). Historical analysis of oil and gas well plugging in New York: Is the regulatory system working? *NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy*, *21*, 103-116. Retrieved from http://baywood.metapress.com/media/16ut607yqg1yrw9ydad3/contributions/b/0/4/7/b047j34r87552325.pdf

natural gas drilling, the report suggested that additional cases of groundwater contamination from hydraulic fracturing may exist.[633]

- April 4, 2011 – *ProPublica* reported that abandoned wells have caused problems across the nation including contamination of drinking water in Colorado, Kentucky, Michigan, New York, Texas, and other states. *ProPublica* also found that a draft report from the Pennsylvania DEP described a 2008 incident in Pennsylvania in which a person died in an explosion triggered by lighting a candle in a bathroom after natural gas had seeped into a septic system from an abandoned well. The same draft report documented at least two dozen additional cases in which gas leaked from old wells, and three in which gas from new wells migrated into old wells, seeping into water supplies and requiring the evacuation of homes.[634]

- May 20, 2010 – The British Columbia Oil and Gas Commission issued a safety advisory after hydraulic fracturing caused a large "kick," or unintentional entry of fluid or gas, into a nearby gas well. The commission reported that it knew of 18 incidents in British Columbia and one in Western Alberta in which hydraulic fractures had entered nearby gas wells. "Large kicks resulted in volumes up to 80 cubic meters [about 100 cubic yards] of fluids produced to surface. Invading fluids have included water, carbon dioxide, nitrogen, sand, drilling mud, other stimulation fluids and small amounts of gas." These cases occurred in horizontal wells with a distance between wellbores of up to 2,300 feet. The Commission wrote, "It is recommended that operators cooperate through notifications and monitoring of all drilling and completion operations where fracturing takes place within 1000m [3,280 feet] of well bores existing or currently being drilled." Such communication between active wells raises the potential that similar communication can occur between active wells and abandoned wells.[635]

- 2010 – The NYS DEC cautioned that "abandoned wells can leak oil, gas and/or brine; underground leaks may go undiscovered for years. These fluids can contaminate ground and surface water, kill vegetation, and cause public safety and health problems." As the agency reported, "DEC has at least partial records on 40,000 wells, but estimates that over 75,000 oil and gas wells have been drilled in the State since the 1820s. Most of the wells date from before New York established a regulatory program. Many of these old wells were never properly plugged or were plugged using older techniques that were less reliable and long-lasting than modern methods."[636] The agency published similar comments in 2008 and 2009.

- January 2009 – In a presentation before the Society of Petroleum Engineers, industry consultant Michael C. Vincent reported on evidence that fractures from hydraulically

[633] Urbina, I. (2011, August 4). A tainted water well, and concern there may be more. *The New York Times.* Retrieved from http://www.nytimes.com/2011/08/04/us/04natgas.html
[634] Kusnetz, N. (2011, April 4). Danger in honeycomb of old wells. *Pittsburgh Post-Gazette*. Retrieved from http://www.post-gazette.com/nation/2011/04/04/Danger-in-honeycomb-of-old-wells/stories/201104040149
[635] British Columbia Oil & Gas Commission. (2010, May 20). Safety advisory: communication during fracture stimulation. Retrieved from https://www.bcogc.ca/node/5806/download
[636] New York State Department of Environmental Conservation. (2010). New York oil, gas and mineral resources 2010. Retrieved from http://www.dec.ny.gov/docs/materials_minerals_pdf/10anrpt1.pdf

fractured wells can communicate with nearby oil and gas wells. In spite of numerous examples of fractures intersecting with adjacent wellbores, the industry is reluctant to publish reports documenting these cases because "such information could unnecessarily alarm regulators or adjacent leaseholders." Vincent added, "Although computing tools have improved, as an industry we remain incapable of fully describing the complexity of the fracture, reservoir, and fluid flow regimes." These findings raise the possibility that there could be similar communications between existing fracked wells that are fractured and abandoned wells and that operators cannot accurately predict how these will interact.[637]

- 2005 – M.K. Fisher, Vice President of Business Management at Pinnacle, a service of Halliburton that specializes in hydraulic fracturing, reported in an article published by the Society of Petroleum Engineers that a single fracture produced during a fracking operation in the Texas Barnett Shale had unexpectedly spread 2,500 feet laterally in two directions. He also described fractures in the Barnett Shale as "extremely complex."[638] These findings raise the possibility that well communication over very large distances could occur due to fractures that spread "unexpectedly."

- October 1999 – The U.S. Department of Energy reported that there were approximately 2.5 million abandoned oil and gas wells in the U.S.[639]

- Early 1990s – An underground waste disposal well in McKean County, Pennsylvania, contaminated groundwater when the wastewater traveled up a nearby abandoned, unmapped, and unplugged oil well. Owners of private water wells that were contaminated by the incident eventually had to be connected to a public water system.[640]

- July 1989 – In the past, the investigative agency for Congress, the U.S. General Accounting Office (now the Government Accountability Office—GAO) studied oil and natural gas underground injection disposal wells and found serious cases of contamination. The agency reported that, in several cases, wastewater from oil and natural gas operations had migrated up into abandoned oil and natural gas wells, contaminating underground water supplies. The GAO found that "if these abandoned wells are not properly plugged—that is, sealed off —and have cracked casings, they can serve as pathways for injected brines [waste fluids from natural gas and oil drilling] to enter drinking water…. Because groundwater moves very slowly, any contaminants that

[637] Vincent, M. C. (2009, January 19). Examining our assumptions – Have oversimplifications jeopardized our ability to design optimal fracture treatments? Lecture presented at Society of Petroleum Engineers hydraulic fracturing technology conference in The Woodlands, Texas. See http://www.spe.org/dl/docs/2010/MikeVincent.pdf
[638] Fisher, M., Wright, C., Davidson, B., Steinsberger, N., Buckler, W., Goodwin, A., & Fielder, E. (2005). Integrating fracture-mapping technologies to improve stimulations in the Barnett Shale. *SPE Production & Facilities*, *20*(2). doi: 10.2118/77441-PA
[639] United States Department of Energy, Office of Fossil Energy. (1999, October 5). *Environmental benefits of advanced oil and gas exploration and production technology*. (Rep.). Retrieved from http://www.netl.doe.gov/kmd/cds/disk25/oilandgas.pdf
[640] Hopey, D. (2012, January 3). Wastewater disposal wells under scrutiny following Irvin leak. *Pittsburgh Post-Gazette*. Retrieved from http://www.post-gazette.com/news/environment/2012/01/03/Wastewater-disposal-wells-under-scrutiny-following-Irvin-leak.html

enter it will remain concentrated for long periods of time, and cleanup, if it is technically feasible, can be prohibitively costly."[641]

- December 1987 – The EPA submitted a report to Congress on oil and natural gas wastes in which the agency cautioned that abandoned wells must be plugged with cement in order to avoid "degradation" of ground and surface waters as a result of pressurized brine or injected waste from wastewater disposal wells migrating into to aquifers, rivers, or streams.[642] While the EPA did not address the potential for contamination through abandoned wells as a result of hydraulic fracturing, both hydraulic fracturing and underground injection disposal wells require underground injection of fluid under pressure, raising the potential that there is a similar risk of groundwater contamination when hydraulic fracturing occurs near abandoned wells.

- 1985 – In an investigation of 4,658 complaints due to oil and natural gas production, the Texas Department of Agriculture found that "when a water well is experiencing an oilfield pollution problem (typically, high chlorides), the pollution source is often difficult to track down. The source could be a leak in the casing of a disposal well, leakage behind the casing due to poor cement bond, old saltwater evaporation pits, or, most often, transport of contaminants through an *improperly plugged abandoned well*" (emphasis in original). The agency found more than a dozen confirmed or suspected cases in which pollutants had migrated up abandoned wells and contaminated groundwater. In one case, drilling wastewater migrated up an abandoned well a half mile away from where the wastewater was injected underground for disposal.[643]

- November 1978 – In a report later cited by the EPA in its 1987 report to Congress (cited above), the state of Illinois Environmental Protection Agency found that oil and natural gas wastes injected underground could migrate through abandoned oil and natural gas wells and contaminate groundwater. The agency wrote, "In old production areas, abandoned wells may pose a serious threat to ground water quality. Unplugged or improperly plugged wells provide possible vertical communication between saline and fresh water aquifers."[644]

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[641] United States Government Accountability Office. (1989, July 5). Drinking water: Safeguards are not preventing contamination from injected oil and gas wastes. Retrieved from http://www.gao.gov/products/RCED-89-97. (2, 4, Rep.).
[642] U.S. Environmental Protection Agency. (1987). *Report to Congress: Management of wastes from the exploration, development, and production of crude oil, natural gas, and geothermal energy* (III-47, Rep.). Retrieved from http://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=20012D4P.pdf
[643] Texas Department of Agriculture, Department of Natural Resources. (1985). *Agricultural land and water contamination: From injection wells, disposal pits, and abandoned wells used in oil and gas production* (pp. 5, 12-15). Austin, TX: Dept. of Agriculture, Office of Natural Resources.
[644] Illinois Environmental Protection Agency, Water Quality Management Planning. (1978). *Illinois oil field brine disposal assessment* (pp. 44-45, Rep.).

Flood risks

Fracking exacerbates flood risks in two ways. First, massive land clearing and forest fragmentation that necessarily accompany well site preparation increase erosion, run-off, and risks for catastrophic flooding. The construction of access roads, easements for pipelines, and build-out of other related infrastructure further contribute to the problem. Compared to an acre of forest or meadow, an acre of land subject to fracking construction activity releases 1,000-2,000 times more sediment during rainstorms. In addition, in some cases, operators choose to site well pads on flood-prone areas in order to have easy access to water for fracking, to abide by setback requirements intended to keep well pads away from inhabited buildings, or to avoid productive agricultural areas.

Second, the vulnerability of fracking sites to flooding increases the known dangers of unconventional gas extraction, heightening the risks of contamination of soils and water supplies, the overflow or breaching of containment ponds, and the escape of chemicals and hazardous materials. During Hurricane Harvey flooding in Texas in 2017, Eagle Ford operators reported 31 spills at oil and gas wells, storage tanks, and pipelines.

- September 15, 2017 – Hurricane Harvey and its resulting flooding affected various parts of metropolitan Houston's vast oil and gas operations, as well as the Eagle Ford shale region of South Texas. *Reuters* reviewed company reports to the U.S. Coast Guard on the various releases of petrochemicals around the time of Harvey's hit and subsequent flooding. In addition to more than 22,000 barrels of crude oil, gasoline, diesel, drilling wastewater, and petrochemicals spilled from refineries, storage terminals, and other facilities in the days after the storm, 27 million cubic feet (765,000 cubic meters) of natural gas was released.[645] Pipeline operators are required to report oil and gas, but not drilling wastewater, spills to the Texas Railroad Commission. An environmental organization retrieved and listed this data, finding 31 spills at oil and gas wells, storage tanks, and pipelines during the hurricane's flooding. The group notes that though the data contains many "produced water" spills, they are likely underreported since they are not mandatory.[646] More than half the fracking rigs running in the region were estimated to have shut down. "Given that much of oil and gas activity occurs in areas only accessible via dirt roads, the heavy rainfall usually makes the movement of trucks and supplies much more difficult…The trucking and rail of sand, chemicals, and personnel to the well site will all take more time given the likely nasty condition of many Eagle Ford access roads," according to an energy analyst.[647]

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[645] Flitter, E., & Valdmanis, R. (2017, September 15). Oil and chemical spills from Hurricane Harvey big, but dwarfed by Katrina. *Reuters.com.* Retrieved from https://www.reuters.com/article/us-storm-harvey-spills/oil-and-chemical-spills-from-hurricane-harvey-big-but-dwarfed-by-katrina-idUSKCN1BQ1E8

[646] Environment Texas. (2017, September 12). *Report: Environmental and health concerns about oil and gas spills after Hurricane Harvey.* Retrieved from https://environmenttexas.org/sites/environment/files/reports/Harvey%20Oil%20Gas%20Spills%20-%20Env%20TX%20-%209.22.17.pdf

[647] Wethe, D. (2017, August 31). Harvey's floods could delay 10% of U.S. fracking: Analyst. *Bloomberg L.P.* Retrieved from https://www.bloomberg.com/news/articles/2017-08-31/harvey-s-floods-could-delay-10-percent-of-u-s-fracking-analyst

- May 25, 2016 – The removal of photos of flood-related oil spills on a Texas state-run website appears to be an effort to hide visuals that "don't portray the energy business in a flattering light," according to the *El Paso Times* Editorial Board. The photos revealed potential environmental damage caused by flooding at fracking sites.[648] As earlier reported by the *El Paso Times*, many of the photos shot during Texas' recent floods "show swamped wastewater ponds at fracking sites, presumably allowing wastewater to escape into the environment—and potentially into drinking-water supplies."[649]

- May 1, 2016 – Spring floods across Texas inundated oil wells and fracking sites, tipped over storage tanks, and flushed crude oil and fracking chemicals into rivers, as documented in an Associated Press story that referenced dozens of aerial photographs showing flooded production sites along the Sabine River on the Texas-Louisiana border. (The photographs were later removed from direct public access; see above.) Past president of the American Public Health Association Walter Tsou, MD, called the situation "a potential disaster."[650]

- June 12, 2015 – At the beginning of 2015, after a month of record-breaking rainfall, Fish and Wildlife Service officials at the Hagerman National Wildlife Refuge in Texas found that floodwaters flowing through oil production well pads in the refuge had inundated dozens of jackpumps, pipelines, and other oil and gas infrastructure, leaving bubbling, oily water and a gassy stench. In 1989, the U.S. Government Accountability Office (GAO) called for "bold action" to address fossil fuel production activities incompatible with the mission of the refuge system. Subsequent reforms have been exceedingly slow, according to a report from *Greenwire*. In most cases, the Fish and Wildlife Service does not know how much fossil fuel is produced or spilled on refuges, and remediation efforts are inadequate. Severe weather events are expected to increase in frequency and severity as climate change progresses, amplifying flood related concerns.[651]

- June 20, 2014 – The *Coloradoan* reported that Noble Energy storage tanks damaged by spring flooding in Colorado dumped 7,500 gallons of crude oil, fracking chemicals, and fracking wastewater into the Cache la Poudre River, which is both a National Heritage area and a habitat for Colorado's only self-sustaining population of wild trout. Recent high river flows had undercut the bank where the oil tank was located, which caused the tank to drop and break a valve.[652]

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[648] *El Paso Times* Editorial Board. (2016, May 25). Editorial: Hiding bad news from Texans. *El Paso Times.* Retrieved from http://www.elpasotimes.com/story/opinion/editorials/2016/05/25/editorial-hiding-bad-news-texans/84937054/

[649] Schladen, M. (2016, April 30). Flooding sweeps oil, chemicals into rivers. *El Paso Times.* Retrieved from http://www.elpasotimes.com/story/news/2016/04/30/flooding-sweeps-oil-chemicals-into-rivers/83671348/

[650] Siron, C. (2016, May 1). Texas floods washing fracking chemicals, crude oil into rivers. *Dallas Morning News.* Retrieved from http://thescoopblog.dallasnews.com/2016/05/texas-floods-washing-fracking-chemicals-crude-oil-into-rivers.html/

[651] Hiar, C. (2015, June 12). Wildlife refuges: Floods expose weakness in FWS's oil and gas oversight. *E&E Publishing.* Retrieved from http://www.eenews.net/stories/1060020169

[652] Handy, R. (2014, June 20). Crude oil spills into Poudre near Windsor. *Coloradoan.* Retrieved from http://www.coloradoan.com/story/news/local/2014/06/20/crude-oil-spills-poudre-near-windsor/11161379/

- March 2014 – An extraordinary flood that struck the Front Range of Colorado killed ten people, forced the evacuation of 18,000 more, destroyed more than 1,850 homes, and damaged roads, bridges, and farmland throughout the state. More than 2,650 oil and gas wells and associated facilities were also affected, with 1,614 wells lying directly within the flood impact zone. Many of these storm-damaged facilities and storage tanks leaked uncontrollably. In a later accounting, Matt Lepore, Director of the Colorado Oil and Gas Conservation Commission, estimated the flooding had resulted in the release to the environment of 48,250 gallons of oil or condensate and 43,479 gallons of fracking wastewater from 50 different spill sites across the state. In Colorado, more than 20,850 oil and gas wells lie within 500 feet of a river, stream, or other drainage. According to Director Lepore, setback requirements that keep drilling and fracking operations away from residential areas inadvertently encourage operators to drill in unoccupied floodplains. At the same time, oil and gas operators prefer locations close to supplies of water for use in fracking. These twin factors result in a clustering of drilling and fracking operations in low-lying areas prone to catastrophic flooding.[653]

- 2004-2013 – In at least six of the last ten years (2004, 2005, 2006, 2009, 2011, and 2013), several counties targeted for shale gas drilling in New York State have experienced serious flooding. These include the counties of Albany, Broome, Cattaraugus, Chautauqua, Chenango, Delaware, Erie, Greene, Madison, Orange, Otsego, Schoharie, Sullivan and Ulster. In at least five of the past 10 years (2004, 2005, 2006, 2009 and 20011), floods have exceeded 100-year levels in at least some of the counties.[654, 655, 656, 657, 658, 659, 660]

- February 7, 2013 – In its 2012 annual report to investors, oil and gas drilling company Noble Energy stated, “Our operations are subject to hazards and risks inherent in the

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[653] Lepore, M. (2014, March). “Lessons Learned” in the front range flood of September 2013: a staff report to the commissioners of the Colorado Oil and Gas Conservation Commission. Retrieved from the Colorado Oil and Gas Conservation Commission website:
http://cogcc.state.co.us/Announcements/Hot_Topics/Flood2013/FinalStaffReportLessonsLearned20140314.pdf
[654] Brooks, L. T. (2005). *Flood of September 18-19, 2004 in the upper Delaware River basin, New York* (Rep.). Retrieved from United States Geological Survey website: http://ny.water.usgs.gov/pubs/of/of051166/
[655] Suro, T. P., & Firda, G. D. (2006). *Flood of April 2–3, 2005, Neversink River basin, New York* (Rep.). Retrieved from United States Geological Survey website: http://pubs.usgs.gov/of/2006/1319/
[656] Suro, T. P., Firda, G. D., & Szabo, C. O. (2009). *Flood of June 26–29, 2006, Mohawk, Delaware and Susquehanna River basins, New York* (Rep.). Retrieved from United States Geological Survey website: http://pubs.usgs.gov/of/2009/1063/pdf/ofr2009-1063.pdf
[657] Szabo, C. O., Coon, W. F., & Niziol, T. A. (2010). *Flash floods of August 10, 2009, in the villages of Gowanda and Silver Creek, New York* (Rep.). Retrieved from United States Geological Survey website: http://pubs.usgs.gov/sir/2010/5259/pdf/SIR%202010-5259.pdf
[658] Szabo, L. (2011, September 8). *Remnants of Tropical Storm Lee cause record flooding in the Susquehanna River basin* (Rep.). Retrieved from United States Geological Survey website: http://ny.water.usgs.gov/leeindex.html
[659] Giordano, S. (2013, January 29). Several eastern counties in central New York under water after heavy flooding. *Syracuse Post-Standard*. Retrieved from
http://www.syracuse.com/news/index.ssf/2013/06/several_eastern_counties_in_ce.html
[660] New York State Department of Environmental Conservation. (2011). *Supplemental generic environmental impact statement on the oil, gas and solution mining regulatory program, well permit issuance for horizontal drilling and high-volume hydraulic fracturing to develop the Marcellus shale and other low-permeability gas reservoirs* (2-32, 33, Rep.).

drilling, production and transportation of crude oil and natural gas, including … flooding which could affect our operations in low-lying areas such as the Marcellus Shale."[661]

- September 7, 2011 – The New York State Department of Environmental Conservation's (NYS DEC) draft shale gas drilling plan recommended that drilling be prohibited within 100-year floodplains but acknowledged that many areas in the Delaware and Susquehanna River basins that were affected by flooding in 2004 and 2006 were located outside of officially designated flood zones.[662] In 2004, 2005, 2006, 2009, and 2011, flooding in New York exceeded 100-year levels in at least some of the counties where drilling and fracking may occur.

- 1992 – In its Generic Environmental Impact Statement (GEIS) for oil and natural gas drilling, which was predicated on conventional drilling, the NYS DEC raised concerns that storage tanks holding drilling wastewater, spent hydraulic fracturing fluid, or other contaminants could be damaged by flooding and leak. At the time, the GEIS called for at least some of these tanks to be properly secured.[663] Shale gas extraction via horizontal fracking would require many more storage tanks for fracking fluids and wastewater than conventional drilling operations anticipated in 1992 when the agency estimated that oil and gas wells in the state would each require 20,000-80,000 gallons of fracking fluid.[664] As of 2011, the agency anticipated that high volume, horizontally fracked shale gas wells in New York State would each require 2.4-7.8 million gallons of fluid—roughly 100 times the 1992 estimate.[665]

Threats to agriculture and soil quality

Drilling and fracking operations pose risks to the agricultural and timber sectors and damage the ecological value of healthy soils. In California, fracking wastewater illegally injected into aquifers threatens crucial irrigation supplies to farmers in a time of severe drought. Fracking wastewater reused for irrigation and livestock watering in California's San Joaquin Valley may contain at least ten known or suspected chemical carcinogens, as well as over a dozen chemicals

[661] Noble Energy, Annual Report (Form 10-K) (Feb. 7, 2013) at 42.
[662] New York State Department of Environmental Conservation. (2011). *Supplemental generic environmental impact statement on the oil, gas and solution mining regulatory program, well permit issuance for horizontal drilling and high-volume hydraulic fracturing to develop the Marcellus shale and other low-permeability gas reservoirs* (ES-22, 2-32, 33, Rep.).
[663] New York State Department of Environmental Conservation. (2011). *Supplemental generic environmental impact statement on the oil, gas and solution mining regulatory program, well permit issuance for horizontal drilling and high-volume hydraulic fracturing to develop the Marcellus shale and other low-permeability gas reservoirs* (8-42, 8-43, 9-35, Rep.).
[664] New York State Department of Environmental Conservation. (1992). *Generic environmental impact statement on the oil, gas and solution mining regulatory program* (Rep.). Retrieved from http://www.dec.ny.gov/docs/materials_minerals_pdf/dgeisv1ch8.pdf (9-26, Rep.).
[665] New York State Department of Environmental Conservation. (2011). *Supplemental generic environmental impact statement on the oil, gas and solution mining regulatory program, well permit issuance for horizontal drilling and high-volume hydraulic fracturing to develop the Marcellus shale and other low-permeability gas reservoirs* (ES-8, Rep.).

with no available toxicological data and many unidentified compounds currently classified as "trade secrets." Agricultural uses of wastewater, as well as flowback water spills, raise questions about direct exposure of affected soils, contamination of food crops via bioabsorption through plant roots, and impacts on livestock due to ingestion. Studies and case reports from across the country have highlighted instances of deaths, neurological disorders, aborted pregnancies, and stillbirths in farm animals that have come into contact with wastewater. Additionally, farmers have expressed concern that nearby fracking operations can hurt the perception of agricultural quality and invalidate value-added organic certification. Land use changes and transport of invasive species by drilling and fracking operations have led to documented ecological and monetary harm to soils, forests, and natural areas.

- July 20, 2017 – Penn State Unversity researchers identified a direct correlation between the spread of invasive, non-native plants in Pennsylvania's northern forests and specific aspects of fracking operations. Researchers surveyed 127 Marcellus Shale gas well pads and adjacent access roads in seven state forest districts in the Allegheny National Forest. The study "found that within less than a decade invasive non-native plants have spread to over half of the 127 well pads in our survey, and for the 85% of the pads that were less than 4 years old it occurred in a much shorter period of time." Gravel shipments and mud on the tires and undercarriages of trucks carry and deposit seeds and propagules of invasive plants. "Given the fact that on average 1235 one-way truck trips delivering fracturing fluid and proppant are required to complete an unconventional well, the potential to transport invasive plant propagules is significant."[666] "The spread of invasive non-native plants could have long-term negative consequences for the forest ecosystem in a region where the ubiquitous woods provide timbering revenue, wildlife habitat, and ecotourism, warns team member David Mortensen, professor of weed and applied plant ecology."[667]

- May 15, 2017 – By 2015, the annual ecological cost of fracking in the U.S. reached over $272 million per year, according to a team of biologists from Hendrix College in Arkansas. They reached this value by estimating the impact of land-use changes on "ecosystem services," the benefits that natural habitats provide to humans, such as carbon sequestration, flood mitigation, food security, ecotourism revenue, and genetic diversity. Authors considered this estimate to be conservative. In addition, they wrote, "[d]epending on future well-drilling rates, cumulative ecosystem services costs projected to the year 2040 range from US$9.4 billion to US$31.9 billion." Their results showed, "that temperate grassland and deciduous forest are being disproportionately impacted by unconventional oil and gas development. Temperate grasslands are some of the most imperiled ecosystems in North America." They found "considerable variation in

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[666] Barlow, K. M., Mortensen, D. A., Drohan, P. J., & Averill, K. M. (2017). Unconventional gas development facilitates plant invasions. *Journal of Environmental Management, 202*, 208e216. doi: 10.1016/j.jenvman.2017.07.005

[667] Mulhollem, J. (2017, July 20). Shale gas development spurring spread of invasive plants in Pa. forests. *PennState News.* Retrieved from http://news.psu.edu/story/475225/2017/07/20/research/shale-gas-development-spurring-spread-invasive-plants-pa-forests

ecosystem services costs between different plays, with Haynesville, Bakken/Three Forks, and Fayetteville showing the highest annual costs."[668]

- November 29, 2016 – A study by engineers and environmental scientists from China, the U.K., and the Republic of Korea investigated the impact of contaminated fracking flowback water on soil health, using soils from representative shale gas areas in China. They also performed a preliminary human health risk assessment of exposure to the arsenic found in such soils. The solutions they tested were representative of flowback water from various stages following a fracked well's establishment, and their study found that the temporal change in the composition of these wastewaters "leads to different environmental implications." They tested heavy metal mobility and bioaccessibility, finding that even though mobility was reduced by high ionic strength of flowback water, the metals maintained relatively high bioaccessibility. Soil toxicity moderately increased after a month "aging" with the flowback water treatment. Arensic, one of the metals included in the testing, is a known human carcinogen and therefore the focus of the human health risk assessment. Results indicated "a low level of cancer risk through exposure via ingestion."[669]

- October 4, 2016 – A research team from Lawrence Berkeley National Laboratory, University of California Berkeley, and University of the Pacific released preliminary results from a first-ever hazard assessment of chemicals used in California oil drilling operations that reuse wastewater for livestock watering and other agricultural purposes in the San Joaquin Valley. This evaluation, compiled as a technical report by PSE Healthy Energy and Lawrence Berkeley National Laboratory, revealed that more than one-third of the 173 chemicals used are classified as trade secret and their identities are therefore unknown. Of the remainder, ten are classified as either carcinogenic or possibly carcinogenic in humans, 22 are classified by the state of California as toxic air contaminants, and 14 had no ecotoxicity or mammalian toxicity data available. "It is difficult or impossible to estimate risks to consumers, farmworkers or the environment," the authors concluded, "when identification of chemical additives remains in trade secret form and/or lacks toxicity and environmental profile information."[670]

- June 1, 2016 – "Co-contaminant interaction effects" can occur when multiple chemicals are involved in spills of oil and gas wastewater on agricultural soils, according to a study by a Colorado State University research team. Through simulations, researchers analyzed

[668] Moran, M. D., Taylor, N. T., Mullins, T. F., Sardar, S. S., & McClung, M. R. (2017). Land-use and ecosystem services costs of unconventional US oil and gas development. *Frontiers in Ecology and the Environment*, *15*(5), 237–242. doi: 10.1002/fee.1492

[669] Chen, S. S., Suna Y., Tsang, D. C. W., Grahamc, N. J. D., Ok, Y. S., Feng, Y., & Li, X.-D. (2016). Potential impact of flowback water from hydraulic fracturing on agricultural soil quality: Metal/metalloid bioaccessibility, Microtox bioassay, and enzyme activities. *Science of the Total Environment*, *579*, 1419–1426. doi: 10.1016/j.scitotenv.2016.11.141

[670] Shonkoff, S. B. C., Stringfellow, W. T., & Domen, J. K. (2016, September). *Hazard assessment of chemicals additives used in oil field that reuse produced water for agricultural irrigation, livestock watering, and groundwater recharge in the San Joaquin Valley of California: Preliminary results.* Retrieved from https://www.psehealthyenergy.org/wp-content/uploads/2017/04/Preliminary_Results_13267_Disclosures_FINAL-1.pdf

how degradation was affected when combinations of three fracking-related organic chemicals spilled, alone or together: polyethylene glycol, a commonly used surfactant; glutaraldehyde, a biocide to prevent pipe corrosion from microbial activity; and polyacrylamide, a friction reducer. In addition to interactions between the chemicals, they analyzed the role of naturally occurring salts. Results showed that polyethylene glycol surfactants alone can break down in topsoil within 42−71 days, but, in the presence of the biocide glutaraldehyde or salt concentrations typical of fracking wastewater, their biodegradation was impeded or halted altogether. Authors emphasized that the interactions they studied account for only a fraction of the hundreds of fracking chemicals in use, but that their results "show a complex picture of co-contaminant fate and toxicity" that has, so far, been ignored.in the regulatory process.[671]

- December 12, 2015 – A research team at the University of Aberdeen found high levels of selenium, molybdenum, and arsenic in rock samples collected from a region in northern England that has been targeted for fracking. The finding is important due to the possible risk that these toxic elements will be released into groundwater during shale gas operations. Selenium poisoning has occurred among Irish horses confined to pastures underlain by black shale. While small amounts of selenium are essential for metabolism, high levels (which, in the case of human consumption, is above 400 μg/day) are toxic. Possible consequences include neurotoxicity, cancer and diabetes."[672]

- November 23, 2015 – Gas-related impacts on Pennsylvania farmers may include pipelines criss-crossing fields and forests, as well as jeopardization of organic certification, according to a report covering a State Agriculture Department spokesman's presentation, on the Potter County government website. The spokesman said, "steps should be taken to steer this development in ways that diminish impact on soil quality and fragmentation." "With trees and other vegetation being cleared from pipeline rights-of-way, he noted, it's important for the acreage to be replanted with plant species that are beneficial to agriculture—pollinating plants, as an example."[673]

- October 24, 2015 – More than 180 million gallons of wastewater from oil and gas operations spilled from 2009 to 2014, according to an Associated Press analysis of data from leading oil- and gas-producing states (Texas, North Dakota, California, Alaska, Colorado, New Mexico, Oklahoma, Wyoming, Kansas, Utah and Montana). A *Dallas Morning News* report focused on how the resulting contamination of groundwater and soils has affected agricultural and ranching. In one case, wastewater from pits seeped beneath a cotton and nut farm near Bakersfield, California and forced the grower to remove 2,000 acres from production. In western Texas, pipeline failures and illegal

[671] McLaughlin, M. C., Borch, T., & Blotevogel, J. (2016). Spills of hydraulic fracturing chemicals on agricultural topsoil: biodegradation, sorption, and co-contaminant interactions. *Environmental Science & Technology*, *50*(11). doi: 10.1021/acs.est.6b00240
[672] Parnell, J., Brolly, C., Spinks, S., & Bowden, S. (2015). Selenium enrichment in Carboniferous Shales, Britain and Ireland: Problem or opportunity for shale gas extraction? *Applied Geochemistry*, *66*, 82-87. doi*:*10.1016/j.apgeochem.2015.12.008
[673] *Potter County Today.* (2015, November 23). Shale gas impact on agriculture 'profound.' Retrieved from http://today.pottercountypa.net/shale-gas-impact-on-agriculture-profound/

dumping of frack waste contaminated ranches and pastures.[674]

- May 2, 2015 – The *Los Angeles Times* reported that farmers in Kern County, California purchased over 21 million gallons per day of treated oil field wastewater to use for crop irrigation. The article identified lingering questions about chemicals remaining after treatment and their potential impact both on the crops and those who consume them. Independent testing identified chemicals including acetone and methylene chloride, along with oil, in the treated irrigation water.[675] Acetone and methylene chloride are powerful industrial solvents that are highly toxic to humans, and samples of the wastewater contained concentrations of both that were higher than those seen at oil spill disaster sites. (Chevron's own report confirmed the presence of acetone, benzene, and xylene, though in lesser concentrations; Chevron did not appear to test for methylene chloride.[676]) Broader testing requirements involving chemicals covered under California's new fracking disclosure regulations went into effect June 15, 2015.[677]

- April 24, 2015 – Unconventional technologies in gas and oil extraction facilitated the drilling of an average of 50,000 new fractured wells per year in North America over the past 15 years. An interdisciplinary study published in *Science* demonstrated that the accumulating land degradation has resulted in continent-wide impacts, as measured by the reduced amount of carbon absorbed by plants and accumulated as biomass. This is a robust metric of essential ecosystem services, such as food production, biodiversity, and wildlife habitat, and its loss "is likely long-lasting and potentially permanent." The land area occupied by well pads, roads, and storage facilities built during this period is approximately three million hectares, roughly the land area of three Yellowstone National Parks. The authors concluded that new approaches to land use planning and policy are "necessary to achieve energy policies that minimize ecosystem service losses."[678]

- January 26, 2015 – Two Colorado scientists performed a detailed analysis of vegetative patterns—followed chronologically—over a selected group of well pads in Colorado managed by the U.S. Bureau of Land Management, including two undisturbed reference sites. They documented the disturbance of plant and soil systems linked to contemporary oil and gas well pad construction, and found that none of the oil and gas well pads

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[674] Flesher, J. (2015, October 24). Fatal flow: Brine from oil, gas drilling fouls land, kills wildlife at alarming rate. *Dallas Morning News.* Retrieved from http://www.dallasnews.com/news/local-news/20151024-fatal-flow-brine-from-oil-gas-drilling-fouls-land-kills-wildlife-at-alarming-rate.ece

[675] Cart, J. (2015, May 2). Central Valley's growing concern: Crops raised with oil field water. *Los Angeles Times.* Retrieved from http://www.latimes.com/local/california/la-me-drought-oil-water-20150503-story.html#page=1

[676] Amec Foster Wheeler Environment & Infrastructure, Inc. (2015, June 15). Technical report: Reclaimed water impoundments sampling, Cawelo Water District Ponds, Kern River Oil Field, Kern County, California, Prepared for Chevron U.S.A. Inc. Retrieved from https://drive.google.com/file/d/0B1ccgD60cwq7dWE5Y0c2ZDh5WnM/view

[677] Ross, D. (2015, June 19). Has our food been contaminated by Chevron's wastewater? *Truthout.* Retrieved from http://www.truth-out.org/news/item/31470-has-our-food-been-contaminated-by-chevron-s-wastewater

[678] Allred, B. W., Kolby Smith, W., Tridwell, D., Haggerty, J. H., Running, S. W., Naugle, D. E., & Fuhlendorf, S. D. (2015). Ecosystem services lost to oil and gas in North America. *Science, 348* (6233), 401-402.

included in the study returned to pre-drilling condition, even after 20-50 years. Full restoration may require decades of intensive effort.[679]

- October 14, 2014 – State documents obtained by the Center for Biological Diversity show that almost three billion gallons of fracking wastewater have been illegally dumped into central California aquifers that supply drinking water and farming irrigation. The California Water Board confirmed that several oil companies used at least nine of 11 injection wells that connect with high-quality water sources for disposal of fracking wastewater, which included high levels of arsenic, thallium, and nitrates. The California Division of Oil, Gas and Geothermal Resources has shut down 11 oil field injection wells and is scrutinizing almost 100 others for posing a "danger to life, health, property, and natural resources." At least one farming company has sued oil producers in part for contaminating groundwater that farms use for irrigation.[680]

- September 6, 2014 – *Al Jazeera America* examined the challenges that North Dakota farmers are facing in light of wastewater spills from oil and gas development. Notably, in heavily drilled Bottineau County, some levels of chloride, from sites where an estimated 16,800-25,200 gallons of wastewater had seeped into the ground, were so high that they exceeded the levels measurable with the North Dakota Department of Health's test strips. State records, testimonies from oil workers and various residents, and the decades-long failure of contaminated fields to produce crops indicate that wastewater spills are a significant hazard in the current fracking boom.[681]

- August 6, 2014 – The Pennsylvania Department of Environmental Protection (PA DEP) found that leaks of fracking wastewater from three impoundments contaminated soil and groundwater. The findings prompted the state to issue a violation and increase testing.[682]

- August 5, 2014 – Michelle Bamberger, a veterinarian and researcher, and Robert Oswald, a professor of molecular medicine at Cornell University, published a book that describes their research into the impacts of drilling and fracking on agriculture and animal health. They detail results of 24 case studies from six gas drilling states, including follow-up on cases they previously published in the peer-reviewed literature, raising concerns about the effects of drilling and fracking on agriculture and the health of animals.[683]

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[679] Minnick, T. J., & Alward, R. D. (2015). Plant–soil feedbacks and the partial recovery of soil spatial patterns on abandoned well pads in a sagebrush shrubland. *Ecological Applications*, *25*(1), 3-10.
[680] Dechert, S. (2014, October 14). Fracking wastewater spoils California drinking, farm supplies. *Clean Technica*. Retrieved from http://cleantechnica.com/2014/10/14/fracking-wastewater-spoils-california-drinking-farm-supplies/
[681] Gottesdiener, L. (2014, September 6). In shadow of oil boom, North Dakota farmers fight contamination. *Al Jazeera America*. Retrieved from http://america.aljazeera.com/articles/2014/9/6/north-dakota-wastewaterlegacy.html
[682] Hopey, D. (2014, August 6). State: Fracking waste tainted groundwater, soil at three Washington County sites. *Pittsburgh Post-Gazette.* Retrieved from http://www.post-gazette.com/local/washington/2014/08/06/Pa-finds-tainted-water-soil-at-three-Washington-County-shale-sites/stories/201408050198
[683] Bamberger, M., & Oswald, R. (2014). The real cost of fracking: How America's shale gas boom is threatening our families, pets, and food. Boston: Beacon Press.

- August 1, 2014 – At least 19,000 gallons of hydrochloric acid spilled during completion of a fracking well on an alfalfa farm in Kingfisher County, Oklahoma. The Oklahoma Corporation Commission reported concerns about rain pushing chemical runoff into a nearby creek that flows into the town of Hennessey's water system. The responsible company, Blake Production, planned to pay for the alfalfa crop for six years. The landowner and a neighbor were pursuing litigation.[684]

- May 4, 2014 – In an analysis of state data from Colorado, the *Denver Post* reported that fracking related to oil and gas drilling is putting soil quality and farmlands at risk due to significant amounts of toxic fluids penetrating the soil. According to report, 578 spills were reported in 2013, which means that, on average in the state, a gallon of toxic liquid penetrates the ground every eight minutes. Colorado State University soil scientist Eugene Kelly, said that the overall impact of the oil and gas boom "is like a death sentence for soil."[685]

- November 28, 2012 – In conjunction with the Food & Environment Reporting Network, *The Nation* reported that serious risks to agriculture caused by fracking are increasing across the country and linked these concerns to risks to human health.[686]

- January 2012 – A study of gas drilling's impacts on human and animal health concluded that the drilling process may lead to health problems. The study reported and analyzed a number of case studies, including dead and sick animals in several states that had been exposed to drilling or hydraulic fracturing fluids, wastewater, or contaminated ground or surface water.[687] The researchers cited 24 cases in six states where animals and their owners were potentially affected by gas drilling. In one case, a farmer separated 96 head of cattle into three areas, one along a creek where fracking wastewater was allegedly dumped and the remainder in fields without access to the contaminated creek; the farmer found that, of the 60 head exposed to the creek, 21 died and 16 failed to produce, whereas the unexposed cattle experienced no unusual health problems. In another case, a farmer reported that of 140 head of cattle exposed to fracking wastewater, about 70 died, and there was a high incidence of stillborn and stunted calves in the remaining cattle.[688]

- January 2011 – U.S. Forest Service researchers reported dramatic negative effects on vegetation caused by the drilling and fracking of a natural gas well in an experimental

[684] Passoth, K. (2014, August 1). Major oil field spill in Kingfisher Co. *KOCO.com Oklahoma City*. Retrieved from http://www.koco.com/news/major-oil-field-spill-in-kingfisher-county/27236612
[685] Finley, B. (2014, May 4). Colorado faces oil boom "death sentence" for soil, eyes microbe fix. *Denver Post*. Retrieved from http://www.denverpost.com/environment/ci_25692049/colorado-faces-oil-boom-death-sentence-soil-eyes
[686] Royte, E. (2012, November 28). Fracking our food supply. *The Nation*. Retrieved from http://www.thenation.com/article/171504/fracking-our-food-supply
[687] Bamberger, M., & Oswald, R. E. (2012). Impacts of gas drilling on human and animal health. *NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy, 22*(1), 51-77. doi: 10.2190/NS.22.1.e
[688] Ramanujan, K. (2012, March 7). Study suggests hydrofracking is killing farm animals, pets. *Cornell Chronicle*. Retrieved from http://www.news.cornell.edu/stories/2012/03/reproductive-problems-death-animals-exposed-fracking

forest in northeastern West Virginia.[689] In June 2008, the researchers found browning of foliage near the well pad, a lack of ground foliage, and that many trees nearby had dropped their foliage. They attributed these impacts to the loss of control of the wellbore on May 29, 2008, which caused an aerial release of materials from the well. Trees showed no apparent symptoms the following summer.[690] However, the researchers also found "dramatic impacts on vegetation" where drilling and fracking wastewater had been sprayed on the land as a disposal technique following completion of the well. Just after the spraying of approximately 60,000 gallons of wastewater at the first disposal site, the Forest Service researchers found 115 damaged trees and other evidence of harm. This figure grew to 147 trees almost a year later.[691] At a second site, where about 20,000 gallons of wastewater was sprayed, the damage was less dramatic, yet the researchers still found "considerable leaf browning and mortality of young northern red oak seedlings."[692] The researchers concluded that the spraying of the drilling fluids resulted in an "extreme" dose of chlorides to the forest.[693]

- May 2010 – Pennsylvania's Department of Agriculture quarantined 28 cows in Tioga County after the animals wandered through a spill of drilling wastewater and may have ingested some of it. The Department was concerned that beef eventually produced from the cows could be contaminated as a result of any exposure. In May 2011, only ten yearlings were still quarantined, but the farmer who owned the cows, Carol Johnson, told National Public Radio that of 17 calves born to the quarantined cows in the spring of 2011, only six survived, and many of the calves that were lost were stillborn. "They were born dead or extremely weak. It's highly unusual," she said, continuing, "I might lose one or two calves a year, but I don't lose eight out of eleven."[694]

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[689] Adams, M., Edwards, P. J., Ford, W. M., Johnson, J. B., Schuler, T. M., Thomas-Van Gundy, M., & Wood, F. (2011, January). *Effects of development of a natural gas well and associated pipeline on the natural and scientific resources of the Fernow experimental forest* (Rep.). Retrieved from United States Department of Agriculture website: http://www.fs.fed.us/nrs/pubs/gtr/gtr_nrs76.pdf. (1-4, Rep.).
[690] Adams, M., Edwards, P. J., Ford, W. M., Johnson, J. B., Schuler, T. M., Thomas-Van Gundy, M., & Wood, F. (2011, January). *Effects of development of a natural gas well and associated pipeline on the natural and scientific resources of the Fernow experimental forest* (Rep.). Retrieved from United States Department of Agriculture website: http://www.fs.fed.us/nrs/pubs/gtr/gtr_nrs76.pdf. (10-11, Rep.).
[691] Adams, M., Edwards, P. J., Ford, W. M., Johnson, J. B., Schuler, T. M., Thomas-Van Gundy, M., & Wood, F. (2011, January). *Effects of development of a natural gas well and associated pipeline on the natural and scientific resources of the Fernow experimental forest* (Rep.). Retrieved from United States Department of Agriculture website: http://www.fs.fed.us/nrs/pubs/gtr/gtr_nrs76.pdf. (11-15, Rep.)
[692] Adams, M., Edwards, P. J., Ford, W. M., Johnson, J. B., Schuler, T. M., Thomas-Van Gundy, M., & Wood, F. (2011, January). *Effects of development of a natural gas well and associated pipeline on the natural and scientific resources of the Fernow experimental forest* (Rep.). Retrieved from United States Department of Agriculture website: http://www.fs.fed.us/nrs/pubs/gtr/gtr_nrs76.pdf. (15, Rep.).
[693] Adams, M., Edwards, P. J., Ford, W. M., Johnson, J. B., Schuler, T. M., Thomas-Van Gundy, M., & Wood, F. (2011, January). *Effects of development of a natural gas well and associated pipeline on the natural and scientific resources of the Fernow experimental forest* (Rep.). Retrieved from United States Department of Agriculture website: http://www.fs.fed.us/nrs/pubs/gtr/gtr_nrs76.pdf. (17, Rep.).
[694] Phillips, S. (2011, September 27). Burning questions: Quarantined cows give birth to dead calves. *StateImpact*. Retrieved from http://stateimpact.npr.org/pennsylvania/2011/09/27/burning-questions-quarantined-cows-give-birth-to-dead-calves/

- March 2010 – A Pennsylvania State Extension analysis of dairy farms in the state found a decline in the number of dairy cows in areas where fracking was prevalent. Pennsylvania counties that had both more than 10,000 dairy cows and more than 150 Marcellus Shale wells experienced a 16-percent decline in dairy cows between 2007 and 2010.[695]

- April 28, 2009 – Seventeen cows in Caddo Parish, Louisiana died within one hour after apparently ingesting hydraulic fracturing fluids spilled at a well that was being fractured. "It seemed obvious the cattle had died acutely from an ingested toxin that had drained from the 'fracking' operation going on at the property," Mike Barrington, a state veterinarian said in a document obtained from the state Department of Environmental Quality by the *Times-Picayune*.[696, 697]

- August 1977 – A paper in the *Journal of Arboriculture* described how natural gas leaks in soil can damage plants and crops. The paper notes that vegetation dies in the vicinity of natural gas leaks. Due to the oxidation of methane by methane-consuming bacteria, gas leaks drive down the oxygen concentration to extremely low levels and cause carbon dioxide concentration to rise. The resulting low oxygen concentration is the greatest contributing factor in the death of trees and other vegetation near natural gas leaks.[698]

Threats to the climate system

Natural gas is not a climate-friendly fuel. Methane, which leaks from all parts of the natural gas extraction and distribution system, is a powerful greenhouse gas that traps 86 times more heat than carbon dioxide over a 20-year time frame. According to the best available evidence, fuel-switching that replaces coal with natural gas to generate electricity offers, at best, no clear climate benefits and may well represent a step backwards. As is now documented in many studies, fugitive methane emissions from U.S. drilling and fracking operations, storage, and ancillary infrastructure are higher than previously supposed. A significant proportion of these leaks are not preventable through engineering fixes. Total methane emissions increased by more than 30 percent between 2002 and 2014. All together, these studies disprove the claim that natural gas is a transitional "bridge" fuel that can lower greenhouse gas emissions while renewable energy solutions are developed.

As both satellite and ground measurements reveal, U.S. methane emissions are responsible for 30-60 percent of the recent upsurge in global atmospheric methane concentrations. Most of this

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[695] Penn State Extension. (2010, March). *Pennsylvania dairy farms and Marcellus shale, 2007–2010* (Rep.). Retrieved from http://cce.cornell.edu/EnergyClimateChange/NaturalGasDev/Documents/PA%20Dairy%20Farms%20and%20Marcellus%202007%20to%202010.pdf

[696] Schleifstein, M. (2011, March 27). Haynesville natural gas field is the most productive in the U.S. *The Times-Picayune*. Retrieved from http://www.nola.com/politics/index.ssf/2011/03/haynesville_natural_gas_field.html

[697] KSLA. (2009, April 28). Cows in Caddo Parish fall dead near gas well. *KSLA News*. Retrieved from http://www.ksla.com/Global/story.asp?S=10268585

[698] Davis, S. H., Jr. (1977). The effect of natural gas on trees and other vegetation. *Journal of Arboriculture, 3*(8),153-154.

excess methane represents fugitive emissions from U.S. oil and gas operations. Many lines of evidence point to the important role of unconventional oil and gas extraction in driving greenhouse gas emissions upward. These include the atmospheric pattern of increased methane concentrations directly over intensively fracked areas of the United States; sharp upticks in global methane and co-occurring ethane levels that correspond to the advent of the U.S. fracking boom; and documentation of large pulses of methane released from storage facilities and other "super-emitting" sites. Further, the widely touted claim that the U.S. fracking boom has contributed to recent declines in carbon dioxide emissions in the United States has been overturned by research showing that almost all of the reductions in CO_2 emissions between 2007 and 2009 were the result of economic recession rather than coal-to-gas fuel switching. Other lines of research show that expanded use of natural gas impedes rather than encourages investments in, and deployment of, renewable energy infrastructure. In sum, fracking, as a major driver of rising methane emissions, is incompatible with climate stability and the goal of rapid decarbonization that it requires.

- October 17, 2017 – Using planes, an international team of researchers measured regional airborne methane and ethane emission rates from the Alberta oil and gas fields in Canada. They compared these results to emissions reported by the industries themselves, as part of an accounting system that requires operators to report flaring and venting volumes, and found large discrepancies. Based on the amounts of methane and ethane detected in the atmosphere above the oil and gas fields, the reported industry emissions in this region should be 2.5 ± 0.5 times higher. Such large discrepancies between actual methane emissions and industry-provided data represent a "reporting gap" and present a critical challenge when determining policy. Proposed regulations in Canada currently call for reducing methane emissions from Canadian fracking operations by 45 percent. However, these data indicate that most of the methane emissions from these operations arise from fugitive leaks that are not being measured at all and/or from episodes of unreported venting.[699]

- July 18, 2017 – A team of 15 climate scientists led by James Hansen at Columbia University conducted a study on the growth rate of greenhouse gas climate forcing, which has accelerated by 20 percent in the past decade. (Climate forcing is the difference between the amount of the sun's energy that is absorbed by the Earth and amount that radiates back into space.) The authors note that methane (CH_4) is the largest climate-forcing gas after carbon dioxide. With an atmospheric lifetime of only about ten years, "there is potential to reduce climate forcing rapidly if CH_4 sources are reduced." However, "there is a danger of increased leakage with expanded shale gas extraction." Noting that the speed of ice sheet melting and sea level rise are difficult to predict, the authors assert that targets for limiting global warming should aim to keep global temperatures close to the preindustrial Holocene range rather than allow them to rise to those found during the prior Eemian period, when sea levels were 6-9 meters higher than today. Such targets require immediate phase-out of fossil fuel emissions, along with

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[699] Johnson, M. R., Tyner D. R., Conley, S., Schwietzke, S., & Zavala-Araiza, D. (2017). Comparisons of airborne measurements and inventory estimates of methane emissions in the Alberta upstream oil and gas sector. *Environmental Science & Technology*. *51*(21), 13008–13017. doi: 10.1021/acs.est.7b03525

profound changes in farming and forestry practices. A delay in taking these measures to minimize irreversible climate impacts means that the next generation will be required to undertake risky, expensive, large-scale CO_2 extraction practices, such as carbon capture. "If high fossil fuel emissions continue, a great burden will be placed on the young. . . . Continued high fossil fuel emissions unarguably sentences young people to either a massive, implausible cleanup or growing deleterious climate impacts or both."[700]

- July 8, 2017 – An investigative report from the Inter Press Service News Agency examined the climate impacts of methane emissions from Mexico, which is sixth among the world's nations in technically recoverable shale gas reserves (after China, Argentina, Algeria, the United States, and Canada). Mexico's current energy policy, introduced in 2014, emphasizes the exploitation of shale gas using fracking. Using data from the state-owned energy company Petroleos Mexicanos (PEMEX), the Inter Press Service story documents that as of 2017, more than 900 wells, located in six of Mexico's 32 states, have been drilled and fracked. High volumes of methane are emitted during venting, and methane emissions have been increasing sharply. In 2016, the total methane emissions from Mexico's PEMEX Exploration and Production operations were 641,517 metric tons, 38 percent higher than the previous year. According to researcher Ramón Torres, of the National Autonomous University of Mexico, who is quoted in the story, "Current regulations are based on best practices, but the philosophy of environmental protection has been abandoned. Exploitation is deepening inequities in a negative way, such as environmental impact. It is irresponsible to auction reserves without a proper evaluation of environmental and social impacts."[701]

- June 19, 2017 – A study that measured methane emissions from various components of drilling and fracking equipment on well pads located in four different shale basins in Colorado, Utah, Arkansas, and Wyoming found widely varying results. In Colorado and Utah, a small percentage of well pads leaked the vast majority of methane, whereas leakage was more equitably distributed among wells in Wyoming. The research team also found variations that were dependent on oil/gas/water content as well as on the numbers of wells per well pad. In sum, emissions from well pads contributed significantly to basin-wide methane emissions but varied depending on location. [Note: the authors identify XTO Energy as a cost share partner in this study.][702]

- April 18, 2017 – San Juan Basin in the four-corner region of Utah, Arizona, New Mexico, and Colorado, is one of the largest coal-bed methane producing regions in North America. Between 2003 and 2015, natural gas production declined, and yet, as revealed by atmospheric sampling from aircraft flying over the basin, methane emissions did not decrease during this same time period. These results confirm earlier findings from a

[700] Hansen, J., Sato, M., Kharecha, P., von Schuckmann, K., Beerling, D. J., Cao, J. . . . Ruedy, R. (2017). Young people's burden: Requirement of negative CO2 emissions. *Earth System Dynamics, 8,* 577-616. doi: 10.5194/esd-8-577-2017

[701] Godoy, E. (2017, July 8). Mexico's methane emissions threaten the environment. *Inter Press Service News Agency.* Retrieved from http://www.ipsnews.net/2017/07/mexicos-methane-emissions-threaten-environment/

[702] Robertson, A. M., Edie, R., Snare, D., Soltis, J., Field, R. A., Burkhart, M. D., … Murphy, S. M. (2017). Variation in methane emission rates from well pads in four oil and gas basins with contrasting production volumes and compositions. *Environmental Science & Technology*, *51*(15), 8832–8840. doi: 10.1021/acs.est.7b00571

satellite study that also showed no declines in regional methane concentrations in spite of significant declines in natural gas production. According to the authors, the likely explanation for the region's persistent, elevated methane levels is increased oil drilling in the basin.[703]

- February 9, 2017 – Using ground-based monitoring methods, a team led by Drexel University researchers monitored a range of emissions, including methane, in two intensively drilled regions of the Marcellus Shale basin in Pennsylvania. The goal was to understand the concentrations and sources of relevant air pollutants that had previously been reported as impacts of drilling and fracking operations. Airborne methane concentrations were higher in southwestern Pennsylvania as compared to northeastern Pennsylvania. The authors conclude that urban-like levels of air pollutants in rural Pennsylvania are likely due to emissions from oil and gas operations in the Marcellus Shale basin.[704]

- January 9, 2017 – A modeling study found that short-lived greenhouses gases, such as methane, contribute to thermal expansion of the ocean over much longer time scales than their brief atmospheric lifetimes might otherwise predict. "Actions taken to reduce emissions of short-lived gases could mitigate centuries of additional future sea-level rise."[705]

- December 12, 2016 – As part of the interdisciplinary Global Carbon Project, a consortium of scientists undertook a meta-analysis that synthesizes many hundreds of individual studies in order to better understand the global methane cycle. Integrating atmospheric measurements with ground-based data, the researchers found more uncertainty in the emissions from natural sources than from human activities. For the 2003–2012 decade, global methane emissions were 558 teragrams per year (range of 540–568), with 60 percent of global methane emissions attributed to anthropogenic sources of all kinds and with a significant contribution (likely at least 39 percent) from oil and gas production operations.[706]

- December 12, 2016 – An editorial published in *Environmental Research Letters* by an international team of scientists urges immediate attention to quantify and reduce methane emissions. "Unlike CO2, atmospheric methane concentrations are rising faster than at any time in the past two decades and, since 2014, are now approaching the most greenhouse-gas-intensive scenarios." The authors present methods of evaluating anthropogenic and

[703] Smith, M. L., Gvakharia, A., Kort, E. A., Sweeney, C., Conley, S. A., Faloona, I., … Wolter, S. (2017). Airborne quantification of methane emissions over the four corners region. *Environmental Science & Technology*, *51*(10), 5832–5837. doi: 10.1021/acs.est.6b06107
[704] Goetz, J. D., Avery, A., Werden, B., Floerchinger, C., Fortner, E. C., Wormhoudt, J., … DeCarlo, P. F. (2017) Analysis of local-scale background concentrations of methane and other gas-phase species in the Marcellus Shale.. *Elementa: Science of the Anthropocene,5*(1). doi: https://doi.org/10.1525/ elementa.182
[705] Zickfeld, K., Solomon, S., & Gilford, D. M. (2017) Centuries of thermal sea-level rise due to anthropogenic emissions of short-lived greenhouse gases. *Proceedings of the National Academy of Sciences, 114*(4), 657-662. doi: 10.1073/pnas.1612066114
[706] Saunois, M., Bousquet, P., Poulter, B., Peregon, A., Ciais, P., Canadell, J. G., … Zhu, Q. (2016). The global methane budget 2000–2012. *Earth System Science Data, 8,* 697–751. doi: 10.5194/essd-8-697-2016

biogenic sources of methane, as from agricultural practices and project future methane emissions.[707]

- November 8, 2016 – The government of Scotland released a report confirming that the pursuit of unconventional oil and gas extraction would make more difficult the nation's goal of meeting its climate targets on greenhouse gas emissions.[708]

- November 1, 2016 – A life cycle analysis of greenhouse gas emissions from fracking operations in the Marcellus Shale region found that upstream activities associated with the use and transportation of chemicals, water, and sand mining contributed relatively lower emissions than downstream phases of the fracking process, which include gas combustion, methane leakage, venting, and flaring.[709]

- October 5, 2016 – A new inventory of worldwide methane emissions from various sources finds that methane emissions from the fossil fuel industry are 20-60 percent higher than previously thought.[710] This discovery, based on isotopic fingerprinting of methane sources, has prompted researchers to call for revisions to current climate prediction models and for a renewed emphasis on reducing methane emissions as a necessary tool for combating climate change.[711]

- September 26, 2016 – In ratifying the Paris Climate Agreement, the United States pledged to reduce its greenhouse gas emissions 26-28 percent by 2025 as compared to 2005 levels. A research team from Lawrence Berkeley National Laboratory found that the United States is on track to miss this target, in large part because of soaring methane emissions.[712, 713]

- September 12, 2016 – Using isotopic analysis and archived air samples collected from 1977 to 1998, as well as more contemporary data, a team of researchers from Oregon presented "strong evidence" that methane emissions from fossil fuel sectors were

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707 Saunois, M., Jackson, R. B., Bousquet, P., Poulter, B., & Canadell, J.G. (2016). The growing role of methane in anthropogenic climate change. *Environmental Research Letters, 11,* 120207. doi: 10.1088/1748-9326/11/12/120207
708 Committee on Climate Change. (2016, November 8). Scottish unconventional oil and gas: Compatibility with Scottish greenhouse gas emissions targets. Retrieved from http://www.gov.scot/Resource/0050/00509324.pdf
709 Sibrizzi, C., & LaPuma, P. (2016). An assessment of life cycle greenhouse gas emissions associated with the use of water, sand, and chemicals in shale gas production of the Pennsylvania Marcellus Shale. *Journal of Environmental Health, 79*(4), 8-15. Retrieved from https://www.neha.org/node/58673
710 Schwietzke, S., Sherwood, O. A., Bruhwiler, L. M. P., Miller, J. B., Etiope, G., Dlugokencky E. J., . . . Tans, P. P. (2016). Upward revision of global fossil fuel methane emissions based on isotope database. *Nature, 538*. 88-91. doi: 10.1038/nature19797
711 Vaughan, A. (2016, October 5). Fossil fuel industry's methane emissions far higher than thought. *The Guardian.* Retrieved from https://www.theguardian.com/environment/2016/oct/05/fossil-fuel-industrys-methane-emissions-far-higher-than-thought
712 Greenblatt, J. R., & Wei, M. (2016). Assessment of the climate commitments and additional mitigation policies of the United States. *Nature Climate Change, 6,* 1090-93. doi: 10.1038/nclimate3125
713 Mooney, C. (2016, September 26). The U.S. is on course to miss its emissions goals, and one reason is methane. *The Washington Post.* Retrieved from https://www.washingtonpost.com/news/energy-environment/wp/2016/09/26/the-u-s-is-on-course-to-miss-its-emissions-goals-and-one-reason-is-methane/?utm_term=.80df24676a21

approximately constant in the 1980s and 1990s but then increased significantly between 2000 and 2009. Over the same time period, methane emissions from biomass burning, rice cultivation, and wetlands decreased. These results contradict the findings of earlier studies that used atmospheric ethane as a marker for methane and had concluded that fugitive fossil fuel emissions fell during much of that period. (More recent studies show that ethane emissions are increasing again.)[714, 715, 716]

- July 11, 2016 – A group of 130 environmental and health organizations signed a formal complaint with the Inspector General of the U.S. Environmental Protection Agency (EPA) about a pivotal 2013 study that was published in the *Proceedings of the National Academies of Sciences* and which was led by University of Texas chemist David T. Allen. The letter accused Allen of "systemic fraud, waste, and abuse" for his reliance on an inaccurate measurement device that was known to underestimate methane levels. Partially funded by the oil industry, Allen's study reported very low methane emission rates as part of a large survey of 190 drilling and fracking sites across the nation. That flawed study was influential, said complainants, in preventing EPA from recognizing the magnitude of methane leakage from drilling and fracking operations.[717] (See also the entry below for March 24, 2015.)

- June 17, 2016 – A comparative assessment of emerging methods for measuring methane emissions from different sources recommends combining analytic methods with chemical mass balance (CMB) methods. The CMB system is currently used in the Barnett Shale oil and gas production region in Texas as an approach to tracing methane emissions back to their sources.[718]

- May 25, 2016 – As part of the first field study to directly measure methane emissions from the heavily drilled Bakken Shale formation in northwestern North Dakota, a team led by atmospheric chemist Jeff Peischl at the National Oceanic and Atmospheric Administration (NOAA) flew research aircraft over the region in May 2014. The researchers derived a methane emission rate of 275,000 tons of methane per year, which is similar to the rate of methane leakage in the Front Range area of Colorado but significantly lower than previous studies of the Bakken area that relied on satellite remote sensing data during an earlier time period (2006-2011). Analyzing the chemical

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714 Rice, A. L., Butenhoff, C. L., Teama, D. G., Röger, F. H., Khalil, M. A. K., & Rasmussen, R. A. (2016). Atmospheric methane isotopic record favors fossil sources flat in 1980s and 1990s with recent increase. *Proceedings of the National Academy of Sciences,113*(39). 10791–10796. doi: 10.1073/pnas.1522923113

715 Harvey, C. (2016, September 13). Scientists may have solved a key mystery about the world's methane emissions. *The Washington Post.* Retrieved from https://www.washingtonpost.com/news/energy-environment/wp/2016/09/13/the-answer-to-the-global-methane-mystery-fossil-fuels-a-study-finds/?utm_term=.64a94b9abf4e

716 von Kaenel, C. (2016, September 13). Debate rises over real source of higher methane emissions. *Scientific American.* Retrieved from https://www.scientificamerican.com/article/debate-rises-over-real-source-of-higher-methane-emissions/

717 Johnson, J. (2016, July 11). Pivotal study on methane leaks from U.S. oil and natural gas wells under fire. *Chemical & Engineering News.* Retrieved from http://cen.acs.org/articles/94/i28/Pivotal-study-methane-leaks-US.html

718 Allen, D. (2016). Attributing atmospheric methane to anthropogenic emission sources. *Accounts of Chemical Research, 49,* 1344−1350. doi: 10.1021/acs.accounts.6b00081

composition of air samples, the NOAA team determined that almost all of the methane originated with oil and gas operations, rather than with natural or agricultural sources, and estimated a leakage rate of 4.2-8.4 percent.[719] Scaled to production, this emission rate is slightly lower than that estimated by EPA in its recently revised inventory.[720, 721] (See April 15, 2016 entry below.)

- April 15, 2016 – In its 21st annual greenhouse gas inventory, which includes 2014 data, the EPA increased its leakage assessment from oil and gas operations by 34 percent. For oil production alone, the EPA more than doubled its estimates of methane emissions. Further, in an admission that the agency had been historically underestimating methane leaks, the EPA also retroactively increased estimates of past emissions from the fossil fuel sector as expressed in prior inventories.[722, 723] In an accompanying news release, the agency said, "Data on oil and gas show that methane emissions from the sector are higher than previously estimated. The oil and gas sector is the largest emitting-sector for methane and accounts for a third of total U.S. methane emissions."[724] Past EPA inventories had identified livestock as the number one source of U.S. methane. These annual inventories fulfill the EPA's obligations under the United Nations Framework Convention on Climate Change, signed and ratified by the United States in 1992, and attempt to identify and quantify U.S. anthropogenic sources and sinks of greenhouse gases for the time period 1990 and forward. The upward revision in both past and current inventories is a reflection of changing methodologies for measuring methane leaks.[725] Older methods included the incorporation of "bottom-up" data supplied by the oil and gas industry, without attention to high-emitting or super-emitting sources or possible sources of error introduced by flawed measuring equipment. In addition, the use of a Global Warming Potential multiplier of 25 for methane, which is based on a 100-year time

[719] Peischl, J., Karion, A., Sweeney, C., Kort, E. A., Smith, M. L., Brandt, A. R., . . . Ryerson, T. B. (2016). Quantifying atmospheric methane emissions from oil and natural gas production in the Bakken shale region of North Dakota. *Journal of Geophysical Research: Atmospheres, 121*. doi: 10.1002/2015JD024631

[720] National Oceanic and Atmospheric Administration. (2016, May 16). *North Dakota's Bakken oil and gas field leaking 275,000 tons of methane per year* [Press release]. Retrieved from http://www.noaa.gov/news/north-dakota-s-bakken-oil-and-gas-field-leaking-275000-tons-of-methane-year

[721] MacPherson, J. (2016, May 11). A new study says the oil-producing region of North Dakota and Montana leaks 275,000 tons of methane annually. *U.S. News & World Report.* Retrieved from http://www.usnews.com/news/science/articles/2016-05-11/study-bakken-oil-field-leaks-275-000-tons-of-methane-yearly

[722] U.S. Environmental Protection Agency. (2016, April 15). *Inventory of U.S. greenhouse gas emissions and sinks: 1990-2014.* Retrieved from https://www.epa.gov/sites/production/files/2016-04/documents/us-ghg-inventory-2016-main-text.pdf

[723] Johnson, J. (2016, April 25). Oil, natural gas operations now top U.S. methane emitters. *Chemical & Engineering News.* Retrieved from http://cen.acs.org/articles/94/i17/Oil-natural-gas-operations-top.html?type=paidArticleContent

[724] U.S. Environmental Protection Agency. (2016, April 15). *EPA publishes 21st annual U.S. greenhouse gas inventory* [Press release]. Retrieved from https://www.epa.gov/newsreleases/epa-publishes-21st-annual-us-greenhouse-gas-inventory

[725] Mooney, C. (2016, April 15). The U.S. has been emitting a lot more methane than we thought, says EPA. *The Washington Post.* Retrieved from https://www.washingtonpost.com/news/energy-environment/wp/2016/04/15/epa-issues-large-upward-revision-to-u-s-methane-emissions/?utm_term=.eca9c599ff09

horizon, rather than 86 for a 20-year time horizon, has come under sustained criticism given the urgency of the climate crisis.[726, 727]

- April 7, 2016 – Since 2009, corresponding to the advent of the U.S. shale gas boom, North American ethane emissions have increased by 5 percent per year. This trend represents a reversal of a previous multi-decade decline (mid-1980s until the end of the 2000s) in the abundance of atmospheric ethane that had been attributed to the reduction of fugitive emissions from fossil fuel sources. These are the findings of an international research team, which analyzed remote sensing data gathered by the Network for the Detection of Atmospheric Composition Change at globally distributed ground-based sites. Ethane is a volatile organic compound (VOC) that readily reacts with nitrogen oxides in the presence of sunlight to create ground-level ozone (smog). Also a potent greenhouse gas, ethane is co-released along with methane from drilling and fracking sites. The source of two-thirds of the ethane in Earth's atmosphere is leakage from natural gas wells and pipelines. Because ethane is co-emitted with methane and can serve as a marker for it, this documentation of a sharp, recent uptick in atmospheric ethane is part of a larger body of evidence suggesting that U.S. drilling and fracking operations are driving up global methane levels.[728] (See also entry dated June 13, 2016 in Air Pollution section].)

- April 5, 2016 – A research team using infrared cameras and helicopters demonstrated that between 1 and 14 percent of oil and gas well pads surveyed were high emitters of hydrocarbons and VOCs, with the greatest number observed in oil producing areas and in areas with horizontal drilling.[729] While some emissions were intentional or part of routine maintenance operations, fugitive, unplanned releases (as from malfunctioning equipment) were also common, as were combustion emissions (as from flares and compressor engine exhaust). Tank vents and hatches were the origin of the vast majority (>90 percent) of detected large emission sources, deeply undercutting the assumption in the EPA's Oil & Gas Emission Estimation Tool of 100 percent capture efficiency by tank control systems. While emissions tended to be higher during the first few months of well production, predicting which wells or other sources would become high emitters was not possible. The lead author, speaking to *InsideClimate News*, concluded that the work "really

[726] Sumner, T. (2016, April 14). EPA underestimates methane emissions. *ScienceNews.* Retrieved from https://www.sciencenews.org/article/epa-underestimates-methane-emissions
[727] Profeta, T. (2016, March 3). Study, EPA spotlight methane emissions from oil and gas industry. *National Geographic.* Retrieved from http://voices.nationalgeographic.com/2016/03/03/study-epa-spotlight-methane-emissions-from-oil-and-gas-industry/
[728] Franco, B., Mahieu, E., Emmons, L. K., Tzompa-Sosa, Z. A., Fischer, E. V., Sudo, K., … Walker, K. A. (2016). Evaluating ethane and methane emissions associated with the development of oil and natural gas extraction in North America. *Environmental Research Letters*, *11*. doi: 10.1088/1748-9326/11/4/044010
[729] Lyon, D. R., Alvarez, R. A., Zavala-Araiza, D., Brandt, A. R., Jackson, R. B., & Hamburg, S. P. (2016). Aerial surveys of elevated hydrocarbon emissions from oil and gas production sites. *Environmental Science & Technology, 50,* 4877–4886. doi: 10.1021/acs.est.6b00705

demonstrates the importance of things like continuous detection or frequent monitoring to find these high emission sites."[730]

- March 10, 2016 – Attempting to explain a methane plateau between 1999 and 2006 within otherwise almost continuously increasing levels of atmospheric methane since the dawn of the industrial revolution, an international team of atmospheric scientists reconstructed the global history of methane and used isotopic carbon fingerprinting to parse the sources of its emission. Thermogenic emissions were assumed to result from fossil-fuel sources, while biogenic sources were assumed to arise from wetlands and agricultural operations. Based on a geographic distribution of methane revealed by remote sensing, the authors concluded that agricultural emissions, especially increases in livestock inventories and rice cultivation, were the most likely drivers of observed global methane increases from 2006 to 2014.[731] These results stand in contrast to other contemporaneous and recent studies that have supplied evidence for the role of oil and gas extraction in the recent upsurge in atmospheric methane.[732] (See entry for February 16, 2016 below.)

- February 16, 2016 – A Harvard-led team used both satellite retrievals and surface observations to estimate that methane emissions in the United States increased by more than 30 percent over the past twelve years. These findings, which contradict the 10 percent decline reported by the EPA, suggest that the United States could be responsible for 30-60 percent of the recent global spike in atmospheric methane.[733, 734] Since 2015, research on atmospheric methane has frequently relied on an "inverse method" to optimize emission estimates by combining "bottom-up" and "top-down" data, yet data from different sources have not yielded consistent estimates of methane emissions and levels. Three major sources (Wecht et al. [2014], Miller et al. [2013], and Turner et al. [2015]) all found maximum emissions in the South Central United States, with spatial overlaps that made separating livestock sources from oil and gas sources difficult. Taking into account the time period investigated by differing studies reveals an increasing trend in methane emissions, with an increase of 38 percent from 2004 to 2011, a period of greatly increasing drilling activity. This trend is confirmed by analyzing temporal trends in satellite data. While this account still differs from the EPA's inventory in 2014 showing a 3 percent decrease in oil and gas emissions over that same time period, the

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[730] McKenna, P. (2016, April 8). Researchers find no shortcuts for spotting wells that leak the most methane. *InsideClimate News.* Retrieved from https://insideclimatenews.org/news/07042016/big-methane-leaks-superemitters-oil-gas-production-climate-change-edf

[731] Schaefer, H., Fletcher, S. E. M., Veidt, C., Lassey, K. R., Brailsford, G. W., Bromley, T. M., . . . White, J. W. C. (2016, March 10). A 21st century shift from fossil-fuel to biogenic methane emissions indicated by $^{13}CH_4$. *Science.* doi: 10.1126/science.aad2705

[732] McKenna, P. (2016, March 10). The mystery of the global methane rise: Asian agriculture or U.S. fracking? *InsideClimate News.* Retrieved from https://insideclimatenews.org/news/10032016/mysterious-global-methane-rise-asian-agriculture-or-us-fracking

[733] Turner, A. J., Jacob, D. J., Benmergui, J., Wofsy, S. C., Maasakkers, J. D., Butz, A., . . . Biraud, S. C. (2016). A large increase in U.S. methane emissions over the past decade inferred from satellite data and surface observations. *Geophysical Research Letters, 43.* doi: 10.1002/2016GL067987

[734] Magill, B. (2016, February, 16). Study ties U.S. to spike in global methane emissions. *Climate Central.* Retrieved from http://www.climatecentral.org/news/us-60-percent-of-global-methane-growth-20037

EPA's data presumed better control of measured leaks, which may not correlate with better control of overall emissions.

- January 29, 2016 – Working in the Marcellus Shale Basin, a Carnegie Mellon research team compared methane emissions from older conventional gas wells (those that were vertically drilled) and newer, unconventional gas wells (those that combined fracking with horizontal drilling). Measured by facility, the mean emission rate for unconventional wells was 23 times higher than that of conventional wells. This difference, in part, was attributed to the larger size of unconventional well pads, which, typically, have multiple wells per pad, more ancillary equipment, and produce more gas. When corrected for production, the conventional wells leaked more—that is to say, they lost a comparably larger fraction of methane per unit of production—likely due to "unresolved equipment maintenance issues." All together, the authors concluded, these new emissions data show that the recently instituted Pennsylvania Department of Environmental Protection's (PA DEP) methane emissions inventory substantially underestimates facility-level methane emissions. Five unconventional well sites included in this study leaked 10-37 times more methane than estimated in the state inventory.[735]

- January 25, 2016 – Cornell University scientists introduced an innovative methodology for assessing potential climate impacts of alternative choices and used it to demonstrate that emissions of the two most important greenhouse gases (carbon dioxide and methane), calculated as time-integrated radiative forcing, are lower with heat pump water heaters than any other means of heating water. Further, their calculations showed that heat pump water heaters powered by coal-generated electricity achieve greater net climatic benefit than heaters powered by natural gas, while even greater benefits may be achieved by combining heat pump water heaters with electricity generated by renewable sources. The authors proposed and justified a methane emission rate of 3.8 percent for conventional shale gas, which is therefore offered as a lower bound for future, tightly controlled methane emissions from unconventional gas activities. The authors also made their web-based tool for evaluating the greenhouse gas footprint of reference and alternative technologies and its source code available to the public (at http://www.eeb.cornell.edu/howarth/methane/tool.htm).[736]

- December 22, 2015 – To reconcile troubling divergences in published estimates of methane emissions, in which "top-down" estimates, based on atmospheric or satellite sampling, often exceed "bottom-up" estimates, based on ground-level sampling or individual source reports, researchers used a combination of repeated mass balance measurements plus ethane fingerprinting to improve top-down estimates and incorporated a more complete and detailed count of facilities to improve bottom-up estimates.[737] The

[735] Omara, M., Sullivan, M. R., Li, X., Subramanian, R., Robinson, A. L., & Presto, A. A. (2016). Methane emissions from conventional and unconventional natural gas production sites in the Marcellus Shale Basin. *Environmental Science & Technology, 50*. doi: 10.1021/acs.est.5b05503

[736] Hong, B. & Howarth, R. W. (2016). Greenhouse gas emissions from domestic hot water: Heat pumps compared to most commonly used systems. *Energy Science & Engineering, 4*(2), 123-133. doi: 10.1002/ese3.112

[737] Zavala-Araiza, D., Lyon, D. R., Alvarez, R. A., Davis, K. J., Harriss, R. Herndon, S. C., . . . Hamburg, S. P. (2015). Reconciling divergent estimates of oil and gas methane emissions. *Proceedings of the National Academies of Science, 112*(51), 15597-15602. doi: 10.1073/pnas.1522126112

results, as demonstrated in the Barnett Shale oil and gas-producing region of Texas, revealed a convergence of estimates to within 10 percent for fossil methane and 0.1 percent for total methane, with predicted methane emissions 90 percent larger than those estimated by the EPA's Greenhouse Gas Inventory. Exclusion of additional problematic studies might have resulted in even greater convergence and higher estimates.[738] The agreement between top-down and bottom-up estimates demonstrates that well-designed surveys using either approach can be useful, with spatially resolved bottom-up estimates pointing toward production sites as the source of 53 percent of emissions, compressor stations 31 percent of emissions, and processing plants 13 percent of emissions. The Barnett shale emission rate of 1.5 percent calculated in this study is low enough (less than 3 percent) to suggest that gas fired electricity production in this region causes less climate forcing than coal-fired electricity, but it is high enough (greater than 1 percent) to argue against the conversion of diesel powered freight trucks to compressed natural gas. Gas production practices and heavier activity in other basins may lead to higher emission rates, as may the storage and long-distance or very long-distance transmission of natural gas.

- December 22, 2015 – Writing for *Environment & Energy Publishing*, journalist Gayathri Valdyanathan reported on efforts by climate scientists to convince the United Nations to stop expressing the heat-trapping potential of methane over a 100-year time frame and instead use a twenty-year time frame when generating global warming potential, the conversion factor that allows policymakers to compare methane's ability to trap heat with that of carbon dioxide. Methane is a far more potent heat-trapping gas than is carbon dioxide, but it is also shorter lived. By convention, policymakers have used a 100-year time frame when calculating global warming potentials. However, there is no scientific reason to do so, and many scientific critics argue that choosing this time scale veils the true climate impacts of natural gas and "makes the gas appear more benign than it is."[739]

- November 25, 2015 – Using reports from countries and companies with proved reserves of recoverable oil, natural gas, and coal, an analysis published in *Global Environmental Change* shows that full production of these resources would use up 160 percent of the world's estimated remaining carbon budget (designed to restrict anthropogenic climate change to equal to or less than 2^{o} C). While 76 percent of reserves are owned by states or state entities, the relatively smaller amount of reserves owned by investors poses the greater immediate threat, since those companies are more likely poised to produce, refine, and deliver fossil fuels to global markets in the near term. However, exploitation of existing proved reserves controlled by the private sector alone does not lead to warming above the 2^{o} limit, if it is not accompanied by exploration for and development of new reserves. Future considerations of fossil fuel use should focus not only on reducing private sector contributions but also on reducing contributions from countries that have

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738 Song, L. (2015, December 7). Texas fracking zone emits 90% more methane than EPA estimated. *InsideClimate News*. Retrieved from https://insideclimatenews.org/news/07122015/methane-emissions-texas-fracking-zone-90-higher-epa-estimate

739 Vaidyanathan, G. (2015, December 22). Recalculation of leaking methane impacts may affect natural gas market. *E&E Publishing, LLC.* Retrieved from http://www.eenews.net/stories/1060029873

historically dominated or currently dominate emissions, and especially nation-states with large undeveloped reserves.[740]

- November 9, 2015 – Including data available through 2014, the World Meteorological Organization (WMO) reported that globally averaged levels of carbon dioxide, methane, and nitrous oxide reached new highs in 2014, with values, respectively, "143%, 254% and 121% of pre-industrial (1750) levels." [741, 742] While the atmospheric increase in carbon dioxide has slowed, methane and nitrous oxide levels continue to increase. Measurements from the WMO's Global Watch Programme point to wetlands in the tropics and anthropogenic sources at mid-latitudes of the northern hemisphere as the sources of increased methane over the past decade.

- October 8, 2015 – As a foundation for policy recommendations, Cornell University biogeochemist Robert Howarth summarized and analyzed the evidence documenting the magnitude of methane emissions related to oil and gas development in the United States since 2007. With estimated emission rates ranging from 3.8-12 percent, the high radiative forcing of methane over a twenty-year period prevents natural gas from serving as a bridge fuel. Instead of further investments in natural gas, Howarth proposes a rapid transition to electric powered vehicles for transportation, high-efficiency heat pumps for space and water heating, and imposition of a methane tax that is roughly 86 times higher than currently proposed carbon taxes, which typical address only carbon dioxide.[743] Howarth also noted that the EPA "has seriously underestimated the importance of methane emissions in general—and from shale gas in particular."[744]

- August 4, 2015 – A developer of high flow sampling technology determined that a commonly used instrument to quantify methane leakage has unreliable sensors and malfunctions in ways that vastly underreport emissions by factors of three to five. More than 40 percent of the compiled national methane inventory may be affected by this measurement failure, according to the author of this study.[745] The implications of this discovery for our understanding of system-wide methane leakage rates from drilling and fracking operations are not known, but they do call into question the results of at least one major study of methane emissions that relied on this device for collecting data. This

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[740] Heede, R. & Oreskes, N. (2015). Potential emissions of CO_2 and methane from proved reserves of fossil fuels: An alternative analysis. *Global Environmental Change, 36.* Advance online publication. Retrieved from http://dx.doi.org/10.1016/j.gloenvcha.2015.10.005
[741] World Meterological Organization. (2015, November 9). The state of greenhouse gases in the atmosphere based on global observations through 2014. *Greenhouse Gas Bulletin, 11.* Retrieved from http://scifun.chem.wisc.edu/news/ghg-bulletin_2015.pdf?id=8495
[742] Miles, T. (2015, November 9). CO_2 levels hit record high for 30th year in a row. *Scientific American.* Retrieved from https://www.scientificamerican.com/article/co2-levels-hit-record-high-for-30th-year-in-a-row/
[743] Howarth, R. W. (2015). Methane emissions and climatic warming risk from hydraulic fracturing and shale gas development: implications for policy. *Energy and Emission Control Technologies, 3,* 45-54. doi: https://dx.doi.org/10.2147/EECT.S61539
[744] Hauser, A. (2015, October 21). Two studies highlight risks of fracking-released methane. *Weather.com.* Retrieved from https://weather.com/science/environment/news/studies-highlight-risks-of-methane-from-fracking
[745] Howard, T. (2015). University of Texas study underestimates national methane emissions at natural gas production sites due to instrument sensor failure. *Energy Science & Engineering.* Advance online publication. doi: 10.1002/ese3.81

is the second of two studies that finds that the primary tool approved by the U.S. EPA for measuring and reporting emissions of methane fails to function properly when used as directed by the manufacturer. (See also entry below dated March 24, 2015.)

- July 21, 2015 – An international team of researchers investigated the claim that the fracking boom, which has dramatically increased supplies of natural gas in the United States, is the main driver of the modest decline in carbon dioxide emissions since 2007. Conventional wisdom, as expressed by the Third National Climate Assessment of the U.S. Global Change Research Program, attributes the drop in emissions to a shift away from carbon dioxide-intensive coal and toward natural gas in power plants. But this team analyzed the sources of change in carbon dioxide emissions and, using a tool called input-output structural decomposition analysis, documented that the economic downturn, not fuel switching in the power sector, was the explanation for declining carbon dioxide emissions since 2007. The single biggest impact on U.S. emissions was changes in the volume of goods and services consumed. Between 2007 and 2013, driven by a huge drop in the volume of capital investment, emissions associated with capital formation decreased by almost 25 percent. During the same period, emissions related to household consumption decreased by 11 percent.[746]

- July 7, 2015 – A scientific opinion piece by Environmental Defense Fund researchers involved in a group of 11 studies on methane emissions in Texas' Barnett Shale provided an overview and orientation to new research that either measured or estimated methane emissions from oil and gas operations. Research from both top-down estimates (based on measuring atmospheric methane or related compounds at regional or larger scales) and bottom-up measurements (made directly from components or at ground level near studied sites) demonstrated that methane emissions from oil and gas operations in the Barnett Shale region exceeded the emissions expected from the EPA's greenhouse gas inventory, which relies on industry self-reporting and excludes many compressor stations. The new research detailed the importance of addressing high-emitting landfills and natural gas facilities ("super-emitters") and malfunctioning equipment in efforts to control ongoing methane emissions.[747]

- May 28, 2015 – A comprehensive working paper from the New Climate Economy initiative of the Global Commission on the Economy and Climate at Stockholm Environment Institute found that the experience in the United States of substituting natural gas for oil was unlikely to be replicated around the globe and probably will not provide climate benefits unless coupled with strict controls on methane leakage, limits on total energy use, and policies to prevent the displacement of non-fossil fuel energy by methane. Citing multiple studies of the net climate impact of "more abundant, cheaper natural gas supplies," the Commission concluded that "both globally and for the United States, the increase in emissions from the scale effect [from increased energy

[746] Feng, K., Davis, S. J., Sun, L., & Hubacek, K. (2015). Drivers of the US CO_2 emissions 1997-2013. *Nature Communications, 6.* doi: 10.1038/ncomms8714
[747] Harriss, R., Alvarez, R.A., Lyon, D., Zavala-Araiza, D., Nelson, D. & Hamburg, S.P. (2015). Using multi-scale measurements to improve methane emission estimates from oil and gas operations in the Barnett Shale Region, Texas. *Environmental Science & Technology, 49*, 7524-7526. doi: 10.1021/acs.est.5b02305

consumption boosted by cheap natural gas and loss of potentially more expensive lower carbon approaches] fully offsets the emission benefits from the substitution effect, net of methane leakage."[748, 749]

- March 24, 2015 – A University of Cincinnati researcher and independent engineers documented that the Bacharach Hi-Flow Sampler (BHFS)—one of the only tools approved by the EPA for measuring and reporting emissions of methane from natural gas transmission, storage, and processing facilities—failed to function properly when used as indicated by the manufacturer. The BHFS, unless recalibrated daily and running revised software (or taking measurements in a nearly pure methane environment, which is exceedingly rare in the field), misreported high levels of natural gas by as much as an order of magnitude lower than actual concentration. A reanalysis of 2011 results from the City of Fort Worth Air Quality Study revealed at least seven instances for which the BHFS indicated sample concentrations at or below 5 percent when more reliable canister methane readings indicated concentrations that ranged from 6.1 percent to 90.4 percent. Inaccurate measurements like these can contribute to the discrepancy between "top-down" and "bottom-up" measurements of methane, with ground-level measurements from the BHFS potentially producing reports of falsely low emissions.[750] This study was followed by another that further documented malfunctions in the BHFS device and called into question the results of a landmark 2013 survey of methane emissions at 190 drilling and fracking sites across the United States. That 2013 survey, from the University of Texas, relied on the BHFS device for collecting data and found very low leakage rates.[751] (See also entry above dated August 4, 2015.)

- March 20, 2015 – A team led by Bruno Franco from the University of Liege in Belgium discovered an abrupt uptick in ethane levels at a mountaintop station in the Swiss Alps that is far removed from local pollution sources.[752] In a later comment about this discovery, Franco said, "Since 2009, we observed increases of 5% per year here—it was completely unexpected."[753] The team attributed the trend reversal to the natural gas boom

[748] Lazarus, M., Tempest, K., Klevnäs, P., & Korsbakken, J. I. (2015) Natural gas: Guardrails for a potential climate bridge. Stockholm Environment Institute. Retrieved from http://www.sei-international.org/mediamanager/documents/Publications/Climate/NCE-SEI-2015-Natural-gas-guardrails-climate-bridge.pdf

[749] Evans, S. (2015, June 2). The climate benefits of a gas bridge are unlikely to be significant. *Climate Spectator*. Retrieved from http://www.businessspectator.com.au/article/2015/6/2/policy-politics/climate-benefits-gas-bridge-are-unlikely-be-significant

[750] Howard, T., Ferrara, T., & Townsend-Small, A. (2015). Sensor transition failure in the high flow sampler: Implications for methane emission inventories of natural gas infrastructure. *Journal of the Air & Waste Management Association*, *65*(7), 856-862. doi: 10.1080/10962247.2015.1025925

[751] Allen, D. T., Torres, V. M., Thomas, J., Sullivan, D.W., Harrison, M., Hendler, A., . . . Seinfeld, J. H. (2013). Measurements of methane emissions at natural gas production sites in the United States. *Proceedings of the National Academy of Sciences*, 110,17768–17773. doi: 10.1073/pnas.1304880110

[752] Franco, B., Bader, W., Toon, G. C., Bray, C., Perrin, A., Fischer, E. V., . . .& Mahieu, E. (2015). Retrieval of ethane from ground-based FTIR solar spectra using improved spectroscopy: recent burden increase above Jungfraujoch. *Journal of Quantitative Spectroscopy and Radiative Transfer*, *160*, 36-49. http://dx.doi.org/10.1016/j.jqsrt.2015.03.017

[753] Environmental Research Web. (2016, May 23). Ethane emissions back on the rise. Retrieved from http://environmentalresearchweb.org/cws/article/news/65093

in North America. Ethane is released together with methane from drilling and fracking operations and serves as a proxy for it. (See also the entry above for April 7, 2016.)

- March 9, 2015 – With specialized equipment in a mobile van, University of Colorado, the National Oceanic and Atmospheric Administration (NOAA), Environmental Defense Fund, and independent researchers continuously measured methane and ethane from public roads at sites downwind of potential emission sources, such as natural gas production wellheads, processing plants, and compressor stations. The sampling method and modeling allowed capture of multiple "accidental" plumes, acquired during long drives across the study region between planned measurements near large facilities. Sampling was not random but documented a large number of facilities with low methane emission rates (equal to or less than 10 kg/hr), with a smaller yet important number of facilities showing much higher emissions. Although the largest measured emission in this study (1,360 kg/hr) corresponded to approximately $1.2 million in lost revenue per year, the authors noted that, in this industry, the "leak fraction" or "proportional loss" levels they documented would generally translate into only a small proportion of lost revenue, probably not sufficient to prompt strong energy-sector self-regulation.[754]

- March 1, 2015 – Using a simulation model, the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, writing for Germany's Federal Environmental Agency, found that shale gas was not a cheap option to reduce global greenhouse gas emissions. Multiple comparison simulations found that shale gas availability, especially in the short-term, tends to lead to higher emissions due to lower energy prices inducing higher use. The net result is higher costs to achieve compliance with climate targets. In this model, shale gas was also found to compete in an unhelpful way with renewable energy sources, resulting in reduced use of renewable energy sources and reduced investment in energy efficiency measures.[755]

- January 8, 2015 – Using a single integrated modeling program that incorporates detailed estimates of the world's reserves of oil, gas, and coal and is consistent with a wide variety of prior modeling approaches, University College London researchers demonstrated that, around the world, "a third of oil reserves, half of gas reserves and over 80 per cent of current coal reserves should remain unused from 2010 to 2050" in order to meet a target of less than or equal to a 2 degree Celsius rise in global temperature. In addition, "development of resources in the Arctic and any increase in unconventional oil production are incommensurate with efforts to limit average global warming" below the 2 degree threshold. Calling for a "stark transformation" of our understanding of fossil fuel availability, the authors noted that, in a climate-constrained world, fears of scarcity of

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[754] Yacovitch, T. I., Herndon, S. C., Pétron, G., Kofler, J., Lyon, D., Zahniser, M. S., & Kolb, C. E. (2015). Mobile laboratory observations of methane emissions in the Barnett Shale Region. *Environmental Science & Technology, 49,* 7889−7895. doi: 10.1021/es506352j

[755] Kersting, J., Duscha, V., Schleich, J., & Keramidas, K. (2015). The impact of shale gas on the costs of climate policy. Environmental Research of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety. Retrieved from https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/climate_change_03_2015_the_impact_of_shale_gas_1.pdf

fossil fuels must be superseded by a commitment to preventing overuse of existing resources and reserves.[756]

- November 26, 2014 – Stanford University and independent researchers compared coal and natural gas for power generation and concluded that the question of "whether natural gas plants are better than coal plants cannot be answered in the general case." During the period of plant operation, "natural gas plants can produce greater near-term warming than coal plants, with the same power output." They found that over time, natural gas plants can produce some reduction in near-term warming, but only if life cycle methane leakage rates are low and power plant efficiency is high. Relative to coal, there is the potential that "deployment of natural gas power plants could both produce excess near-term warming (if methane leakage rates are high) and produce excess long-term warming (if the deployment of natural gas plants today delays the transition to near-zero emission technologies)."[757]

- October 23, 2014 – Adding to the debate about natural gas and climate change, a multi-center, international research team used a sophisticated, integrated approach to the global energy-economy-climate systems question and found no climate benefit to natural gas over other fossil fuels. As summarized by the editor of *Nature*,

  > The development of hydraulic fracturing technologies has led to rapid growth in the use of natural gas as an energy source. Some evidence has suggested that this growing adoption of natural gas might lead a reduced greenhouse gas burden and consequent mitigation of climate change. This collaboration between five energy–climate modelling teams show that instead—under a scenario of abundant natural gas availability—increased consumption will have little or no impact on climate change." The authors concluded, "although market penetration of globally abundant gas may substantially change the future energy system, it is not necessarily an effective substitute for climate change mitigation policy.[758]

- October 6, 2014 – Utilizing satellite data for the Bakken and Eagle Ford formations, scientists from Germany, the United Kingdom, and the University of Maryland confirmed that higher "top-down" estimates of fugitive methane leaks from oil and gas fields (which are obtained via tall tower flask samples, aircraft measurements, and road surveys) are more accurate than lower "bottom-up" estimates (which are obtained by summing emissions from different types of known sources at sites provided by participating utility companies). According to "bottom-up" estimates, the average U.S. leakage rate ranges from 1.2-2.0 percent. But satellite data show much higher leakage rates: 10.1 percent (± 7.3 percent) and 9.1 percent (± 6.2 percent), for the Bakken and Eagle Ford formations, respectively. These higher estimates indicate that current

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[756] McGlade, C., & Ekins, P. (2015). The geographical distribution of fossil fuels unused when limiting global warming to 2°C. *Nature, 517,* 187-190. doi: 10.1038/nature14016

[757] Zhang, X., Myhrvold, N. P., & Calideira, K. (2014). Key factors for assessing climate benefits of natural gas versus coal electricity generation. *Environmental Research Letters, 9.* doi: 10.1088/1748-9326/9/11/114022

[758] McJeon, H., Edmonds, J., Bauer, N., Clarke, L., Fisher, B., Flannery, B., , … Tavoni, M. (2013). Limited impact on decadal-scale climate change from increased use of natural gas. *Nature, 514,* 482–485. doi: 10.1038/nature13837

inventories likely underestimate fugitive emissions and call into question any immediate climate benefit from switching from coal to natural gas. Similar results were seen for the Marcellus shale region, but as a result of technical and geographical limitations, the authors declined to quantify their results, pending future studies with enhanced equipment.[759]

- September 24, 2014 – According to a paper published by scientists from the University of California and Stanford University, "… without strong limits on [greenhouse gas] emissions or policies that explicitly encourage renewable electricity, abundant natural gas may actually slow the process of decarbonization, primarily by delaying deployment of renewable energy technologies." The study builds on previous research by examining natural gas in a range of supply curves, with a tested economic model, and across three different types and levels of climate policy. Researchers found that abundant natural gas, even with low rates of methane leakage, does little to reduce—and may increase—greenhouse gases. They conclude that delaying deployment of renewable energy technologies "may actually exacerbate the climate change problem in the long term."[760]

- September 2, 2014 – Analyzing the level of greenhouse gas emissions attributable to electricity from natural-gas-fired power plants and coal-fired power plants, economist Chris Busch and physicist Eric Gimon conclude that, over short time frames and at high rates of leakage, natural gas offers little benefit compared to coal and could exacerbate global warming. Although Busch and Gimon acknowledge that natural gas offers some reductions in greenhouse gas emissions over longer time frames, they point out that such reductions are not large enough for natural gas to play an expanded role in efforts to manage emissions. They conclude that under the best of circumstances, natural gas-fired electric power offers a modest benefit toward abating climate change, while if poorly developed (i.e., with extensive methane leaks, estimated by these authors to be on the order of 4 percent or higher), or if used to displace energy efficiency or renewable energy, natural gas could seriously contribute to increased greenhouse gas emissions.[761]

- August 5, 2014 – Reporting in *Scientific American,* the science news organization Climate Central outlined the natural gas-related factors that threaten any ability to achieve climate goals through the proposed Clean Power Plan. "No one has any idea how much methane is leaking from our sprawling and growing natural gas system. This is a major problem, because without a precise understanding of the leak rate natural gas could actually make climate change worse." Referring to an interactive Climate Central tool that runs various methane leakage scenarios, the article notes that, even given modest leak rates and an aggressive transition, "we could still end up with little or no climate

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[759] Schneising, O., Burrows, J. P., Dickerson, R. R., Buchwitz, M., Reuter, M., & Bovensmann, H. (2014). Remote sensing of fugitive methane emissions from oil and gas production in North American tight geologic formations. *Earth's Future, 2*(10), 548–558. doi: 10.1002/2014EF000265
[760] Shearer, C., Bistline, J., Inman, M., & Davis, S. J. (2014). The effect of natural gas supply on US renewable energy and CO2 emissions. *Environmental Research Letters, 9.* doi: 10.1088/1748-9326/9/9/094008
[761] Busch, C. & Gimon, E. (2014). Natural gas versus coal: Is natural gas better for the climate. *The Electricity Journal, 27*(7), 97-111.

benefits by 2030 after an enormous financial and political investment in natural gas."[762]

- July 25, 2014 –EPA's Office of Inspector General reports that the agency "has placed little focus and attention on reducing methane emissions from pipelines in the natural gas distribution sector." According to this report, the EPA acknowledged in 2012 that leaks from natural gas pipelines "accounted for more than 13 million metric tons of carbon dioxide equivalent emissions," are almost 100 percent methane, and represent more than 10 percent of total methane emissions from natural gas systems in the United States. Nevertheless, as report went on to note, the EPA does not have the partnerships in place to begin controlling methane leaks, such as with the Pipeline and Hazardous Materials Safety Administration, nor has it conducted a comprehensive analysis of emissions factors, relying instead on a 1996 study with a "high level of uncertainty."[763]

- May 15, 2014 – A recent review of existing data on life cycle emissions of methane from natural gas systems concluded that, as a strategy for addressing climate change, natural gas is a "bridge to nowhere." The review found that, over a 20-year time frame, natural gas is as bad as or worse than coal and oil as a driver of climate change.[764] Referencing this review and other recent studies, *Bloomberg Business News* reported that the EPA has underestimated the impact of methane leakage resulting from the production, transmission, and distribution of natural gas and is using outdated estimates of methane's potency compared to more recent estimates from the Intergovernmental Panel on Climate Change (IPCC).[765]

- April 25, 2014 – A reassessment of the heat-trapping potential of greenhouse gases revealed that current methods of accounting underestimate the climate-damaging impact of methane pollution from all sources, including drilling and fracking operations.[766]

- April 14, 2014 – A study from researchers at Purdue University, NOAA, Cornell University, University of Colorado at Boulder, and Pennsylvania State University, published in *Proceedings of the National Academy of Sciences* found very high levels of methane emissions above many wells being drilled at fracking sites in Pennsylvania.

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[762] Climate Central. (2014, August 5). Methane leak rate proves key to climate change goals. *Scientific American.* Retrieved from http://www.scientificamerican.com/article/methane-leak-rate-proves-key-to-climate-change-goals/
[763] U.S. Environmental Protection Agency Office of Inspector General. (2014, July 25). *Improvements needed in EPA efforts to address methane emissions from natural gas distribution pipelines*. Report No. 14-P-0324. Retrieved from http://www.epa.gov/oig/reports/2014/20140725-14-P-0324.pdf
[764] Howarth, R. W. (2014). A bridge to nowhere: Methane emissions and the greenhouse gas footprint of natural gas [Abstract]. *Energy Science & Engineering*. doi: 10.1002/ese3.35
[765] Childers, A. (2014, May 9). EPA underestimates fracking's impact on climate change. *Bloomberg*. Retrieved from http://www.bloomberg.com/news/2014-05-09/epa-underestimates-fracking-s-impact-on-climate-change.html
[766] Edwards, M. R. & Trancik, J. E. (2014). Climate impacts of energy technologies depend on emissions timing. *Nature Climate Change, 4,* 348-352. doi: 10.1038/NCLIMATE2204

Levels were 100-1,000 times above the estimates of federal regulators, who have always assumed very low methane emissions as wells are drilled.[767, 768]

- February 26, 2014 – The United Nations' top environmental official, Achim Steiner, argued that the shale gas rush is "a liability" in efforts to slow climate change and that a switch from coal to natural gas is delaying critical energy transition to renewables.[769]

- February 13, 2014 – A major study in *Science* by Stanford University, Massachusetts Institute of Technology, and the U.S. Department of Energy found that methane leaks negate any climate benefits of natural gas as a fuel for vehicles, and that the EPA is significantly underestimating methane in the atmosphere.[770] Lead author Adam R. Brandt told the *New York Times*, "Switching from diesel to natural gas, that's not a good policy from a climate perspective."[771] This study also concluded that the national methane leakage rate is likely between 3.6 and 7.2 percent of production.

- January 15, 2014 – As reported by the *Guardian*, a new study by BP concluded that shale gas "…will not cause a decline in greenhouse gases" and will do little to cut carbon emissions.[772]

- December 30, 2013 – An analysis of fracking-related truck transportation in the Susquehanna River Basin in Pennsylvania found that greenhouse gas emissions from frack water and waste hauling operations were 70-157 metric tons of CO_2 equivalent per gas well.[773]

- November 11, 2013 – In a letter to California Governor Jerry Brown, twenty of the nation's top climate scientists warned that pro-fracking policies will worsen climate disruption and harm California's efforts to be a leader in reducing greenhouse gas

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[767] Caulton, D. R., Shepson, P. B., Santoro, R. L., Sparks, J. P., Howarth, R. W., Ingraffea, A. R., . . . Miller, B. R. (2014). Toward a better understanding and quantification of methane emissions from shale gas development. *Proceedings of the National Academy of Sciences of the United States of America*. doi: 10.1073/pnas.1316546111
[768] Banjeree, N. (2014, April 14). EPA drastically underestimates methane released at drilling sites. *Los Angeles Times*. Retrieved from http://www.latimes.com/science/sciencenow/la-sci-sn-methane-emissions-natural-gas-fracking-20140414,0,2417418.story
[769] Goldenberg, S. (2014, February 26). Achim Steiner: Shale gas rush "a liability" in efforts slow climate change. *Guardian*. Retrieved from http://www.theguardian.com/environment/2014/feb/26/achim-steiner-shale-gas-rush-climate-change-energy
[770] Brandt, A. R., Heath, G. A., Kort, E. A., O'Sullivan, F., Petron, G., Jordaan, S. M., . . . Harriss, R. (2014). Methane leaks from North American natural gas systems. *Energy and Environment*, *343*(6172), 733-735. doi: 10.1126/science.1247045
[771] Davenport, C. (2014, February 13). Study finds methane leaks negate benefits of natural gas as a fuel for vehicles. *The New York Times*. Retrieved from http://www.nytimes.com/2014/02/14/us/study-finds-methane-leaks-negate-climate-benefits-of-natural-gas.html?smid=tw-share
[772] Harvey, F., & Macalister, T. (2014, January 16). BP study predicts greenhouse emissions will rise by almost a third in 20 years. *The Guardian*. Retrieved from http://www.theguardian.com/business/2014/jan/15/bp-predicts-greenhouse-emissions-rise-third?CMP=twt_gu
[773] Gilmore, K. R., Hupp, R. L., & Glathar, J. (2014). Transport of Hydraulic Fracturing Water and Wastes in the Susquehanna River Basin, Pennsylvania. *Journal of Environmental Engineering, 140*. doi: 10.1061/(ASCE)EE.1943-7870.0000810

emissions. The letter called on Governor Brown to place a moratorium on fracking.[774] On November 21, 2013, a group of Governor Brown's former policy and campaign advisors made a similar request in light of concerns about the effects of fracking on climate change and water pollution. [775]

- October 18, 2013 – A team of researchers from multiple institutions including Harvard, the University of Michigan, and NOAA reported that methane emissions due to drilling activities in the south-central U.S. may be almost five times greater than reported by the world's most comprehensive methane inventory. "These results cast doubt on the US EPA's recent decision to downscale its estimate of national natural gas emissions by 25-30 percent," the authors wrote.[776] As the *New York Times* reported, "The analysis also said that methane discharges in Texas and Oklahoma, where oil and gas production was concentrated at the time, were 2.7 times greater than conventional estimates. Emissions from oil and gas activity alone could be five times greater than the prevailing estimate."[777]

- October 18, 2013 – A major study spearheaded by Stanford University's Energy Modeling Forum concluded that fracking and the shale gas revolution will have no long-term climate benefit. The study brought together a working group of about 50 experts and advisors from companies, government agencies, and universities, and modeling teams from 14 organizations. The study also found that build-out of infrastructure for fracking and natural gas will discourage efforts to conserve energy and boost efficiency. The study did not examine methane leaks in order to weigh in on the short-term climate impacts of natural gas.[778]

- October 11, 2013 – As reported in the *Guardian*, key climate scientists argued that the growth in fracking across the United States is hurting the United States' credibility on climate change.[779]

- October 2, 2013 – Updated measurements from the IPCC determined that methane is even worse for the climate than previously thought. The IPCC determined that methane is

[774] Rogers, P. (2013, November 12). Top climate scientists call for fracking ban in letter to Gov. Jerry Brown. *San Jose Mercury News*. Retrieved from http://www.mercurynews.com/ci_24509392/top-climate-scientists-call-fracking-ban-letter-gov
[775] McNary, S. (2013, November 21). Former advisors to Gov. Brown request fracking ban. *Southern California Public Radio*. Retrieved from http://www.scpr.org/blogs/politics/2013/11/21/15248/former-advisors-to-gov-brown-request-fracking-ban/
[776] Miller, S. M., Wofsy, S. C., Michalak, A. M., Kort, E. A., Andrews, A. E., Biraud, S. C., . . . Sweeney, C. (2013). Anthropogenic emissions of methane in the United States. *Proceedings of the National Academy of Sciences, 110*(50), 20018-20022. doi: 10.1073/pnas.1314392110
[777] Wines, M. (2013, November 25). Emissions of methane in U.S. exceed estimates, study finds. *The New York Times*. Retrieved from http://www.nytimes.com/2013/11/26/us/emissions-of-methane-in-us-exceed-estimates-study-finds.html?_r=0
[778] Huntington, H. (2013). Changing the game? Emissions and market implications of new natural gas supplies. *Energy Modeling Forum, 1*. Retrieved from https://emf.stanford.edu/publications/emf-26-changing-game-emissions-and-market-implications-new-natural-gas-supplies
[779] Magill, B. (2013, October 11). Fracking hurts US climate change credibility, say scientists. *Guardian*. Retrieved from http://www.theguardian.com/environment/2013/oct/11/fracking-us-climate-credibility-shale-gas

34 times more potent as a greenhouse gas in the atmosphere than CO2 over a 100-year timeframe, and 86 times more potent over a 20-year timeframe.[780]

- September 27, 2013 – The IPCC formally embraced an upper limit on greenhouse gases for the first time, warning that the world will exceed those levels and face irreversible climatic changes in a matter of decades unless steps are taken soon to reduce emissions. The IPCC reported that humanity faces a “carbon budget”—a limit on the amount of greenhouse gases that can be produced by industrial activity before irreversible, damaging consequences—of burning about a trillion metric tons of carbon. The world is on track to hit that by around 2040 at the current rate of energy consumption.[781]

- August 12, 2013 – A *New Scientist* review of the science on fracking and global warming concluded that fracking could accelerate climate change rather than slow it.[782]

- May 28, 2013 – A research team led by Jeff Peischl, an associate scientist at NOAA and the Cooperative Institute for Research in Environmental Sciences, estimated that methane leakage from Los Angeles-area oil and gas operations was about 17 percent.[783, 784]

- May 2013 – A group of scientists and journalists studying climate change, led by energy systems analyst Eric Larson of Princeton University and the news organization Climate Central, reported that the often-purported 50 percent climate advantage of natural gas over coal is unlikely to be achieved over the next three to four decades given methane leaks and other factors.[785] The 50 percent claim is based on the fact that natural gas produces half as much carbon dioxide when burned than coal, but it ignores the significant greenhouse gas impacts of methane leakage that occurs throughout the life cycle of natural gas production, transmission, and distribution.

- January 2, 2013 – A NOAA study found methane emissions from oil and gas fields in Utah to be as high as nine percent of production. These levels are considered extremely damaging to the climate.[786]

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[780] IPCC. (2013). *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T. F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex & P. M. Midgley (eds.)]. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. doi: 10.1017/CBO9781107415324.
[781] Gillis, J. (2013, September 27). U.N. climate panel endorses ceiling on global emissions. *The New York Times*. Retrieved from http://www.nytimes.com/2013/09/28/science/global-climate-change-report.html?pagewanted=all
[782] Pearce, F. (2013, August 12). Fracking could accelerate global warming. *New Scientist*. Retrieved from http://www.newscientist.com/article/dn24029-fracking-could-accelerate-global-warming.html#.UpEWqsQ3uSo
[783] Peischl, J., Ryerson, T. B., Brioude, J., Aikin, K. C., Andrews, A. E., Atlas, E., . . . Parrish, D. D. (2013). Quantifying sources of methane using light alkanes in the Los Angeles basin, California. *Journal of Geophysical Research: Atmospheres, 118*(10), 4974-4990. doi: 10.1002/jgrd.50413
[784] Ogburn, S. (2014, May 15). Solving the Case of California's Extra Methane. *Scientific American Global RSS*. Retrieved from http://www.scientificamerican.com/article/solving-the-case-of-californias-extra-machine/
[785] Larson, E. D. (2013). Natural gas & climate change. *Climate Central*. Retrieved from http://assets.climatecentral.org/pdfs/NaturalGas-and-ClimateChange.pdf
[786] Tollefson, J. (2013). Methane leaks erode green credentials of natural gas. *Nature, 493*(7430), 12-12. doi: 10.1038/493012a

- November 2012 – A review by the United Nations Environment Programme found that emissions from fracking, as well as other unconventional natural gas extraction methods, could increase global warming in the short-term and be comparable to coal over a 100-year timeframe.[787]

- November 2012 – The International Energy Agency (IEA) found that a large natural gas boom—even with improvements in place to reduce leakage—would eventually lead to greenhouse gas concentrations of 650 parts per million and a global temperature rise of 3.5 degrees Celsius, far exceeding the 2 degree Celsius limit which is critical to avoid the most severe effects of climate change.[788]

- May 29, 2012 – The *Guardian* summarized a special report on natural gas by the IEA: "A 'golden age of gas' spurred by a tripling of shale gas from fracking and other sources of unconventional gas by 2035 will stop renewable energy in its tracks if governments do not take action."[789]

- February 2012 – A study published in *Environmental Research Letters* found that the carbon dioxide emitted from the burning of natural gas —even neglecting the impacts of methane leakage—contributes significantly to greenhouse gas emissions that are driving climate change.[790]

- February 7, 2012 – A NOAA study of Colorado gas fields measured methane emissions of about four percent, a significant percentage that could be very damaging to the climate.[791]

- December 29, 2011 – As reported by the *New York Times*, levels of methane in the atmosphere have been steadily rising since 2007—coinciding with the onset of the fracking boom and posing a serious threat to the Earth's climate.[792]

- October 2011 – A study from the National Center for Atmospheric Research concluded that substituting the use of natural gas for coal will increase, rather than decrease, the rate of global warming for many decades.[793]

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[787] Global Environmental Alert Service. (2012). Gas fracking: Can we safely squeeze the rocks? United Nations Environmental Programme. Retrieved from http://www.unep.org/pdf/UNEP-GEAS_NOV_2012.pdf
[788] World Energy Outlook 2012, (November 2012). *Golden Rules for a Golden Age of Natural Gas—World Energy Outlook Special Report on Unconventional Gas*, International Energy Agency. Retrieved from http://www.iea.org/publications/freepublications/publication/name,27408,en.html
[789] Harvey, F. (2012, May 29). 'Golden age of gas' threatens renewable energy, IEA warns. *Guardian*. Retrieved from http://www.theguardian.com/environment/2012/may/29/gas-boom-renewables-agency-warns
[790] Myhrvold, N. P., & Caldeira, K. (2012). Greenhouse gases, climate change and the transition from coal to low-carbon electricity. *Environmental Research Letters*, *7*(1). doi: 10.1088/1748-9326/7/1/014019
[791] Tollefson, J. (2012, February 7). Air sampling reveals high emissions from gas field. *Nature*. Retrieved from http://www.nature.com/news/air-sampling-reveals-high-emissions-from-gas-field-1.9982
[792] Gillis, J. (2011, December 29). The puzzle of rising methane. *The New York Times*. Retrieved from http://green.blogs.nytimes.com/2011/12/29/the-puzzle-of-rising-methane/
[793] Wigley, T. M. (2011). Coal to gas: The influence of methane leakage. *Climatic Change, 108*(3), 601-608. doi: 10.1007/s10584-011-0217-3

- July 6, 2011 – According to the U.S. Energy Information Administration and other research, significant amounts of methane are leaking from aging gas pipelines and infrastructure.[794]

- April 2011 – A comprehensive analysis of the greenhouse gas footprint of natural gas from shale formations found that between 3.6 percent to 7.9 percent of the methane from natural gas production wells escapes into the atmosphere, rather than being combusted, thereby undermining any climate benefits of gas over coal as a source of energy.[795, 796]

Threats from fracking infrastructure

The infrastructure for drilling and fracking operations is complex, widespread, and poses its own risks to public health and the climate. Beginning where silica sand is mined and processed and ending where gas is burned or liquefied for export, infrastructure includes pipelines, compressor stations, dehydrators, processing plants, rail tankers, flare stacks, and storage deports through which oil or gas is moved, filtered, pressurized, warehoused, refined, and vented. It also includes injection wells and recycling facilities that dispose and treat the prodigious amounts of liquid waste that fracking generates. Air pollution is produced at every stage of the process.

In the Upper Midwest, the boom in silica sand mining threatens both air and water quality. It has transformed rural areas into industrialized zones and introduced complex public health risks that are not well understood. Wisconsin alone provides more than half the sand used in fracking operations in the United States. Silica dust is a well-known cause of both lung cancer and silicosis. Precise exposures to downwind communities are unknown at this writing.

Compressor stations and pipelines are major sources of air pollutants, including benzene and formaldehyde, constituting potential health risks to those living nearby while offering no offsetting economic benefits. Instead, they are associated with loss of tax revenue and economic development for the communities where they are sited and traverse. The Medical Society of the State of New York and the American Medical Association have each called for comprehensive health impact assessments regarding the health and safety risks associated with natural gas pipelines, which include fires, explosions, and leaks.

Gas storage facilities include not only manmade holding tanks but also geological formations, most notably, abandoned salt caverns and depleted oil fields left over from mining and drilling operations. These unlined cavities were not created with the intent to store pressurized hydrocarbon gases, nor are they engineered for this purpose. The 3,600-acre Aliso Canyon gas

[794] McKenna, P. (2011, July 6). Thousands of gas leaks under Boston and San Francisco. *New Scientist*. Retrieved from http://www.newscientist.com/article/mg21128203.800-thousands-of-gas-leaks-under-boston-and-san-francisco.html#.UpEbbMQ3uSp
[795] Howarth, R. W., Santoro, R., & Ingraffea, A. (2011). Methane and the greenhouse-gas footprint of natural gas from shale formations. *Climatic Change, 106*(4), 679-690. doi: 10.1007/s10584-011-0061-5
[796] Howarth, R. W., Santoro, R., & Ingraffea, A. (2012). Venting and leaking of methane from shale gas development: Response to Cathles et al. *Climatic Change, 113*(2), 537-549. doi: 10.1007/s10584-012-0401-0

storage facility, located in a depleted oil field in southern California, released more than 100,000 metric tons of methane into the air of the San Fernando Valley over a four-month period beginning in October 2015 before it was finally contained in February 2016. This massive methane leak—the largest in U.S. history—is the greenhouse gas equivalent of a half million cars driving for a year. The plume itself was visible from space. More than 8,000 families in the nearby community of Porter Ranch were evacuated and relocated, thousands were sickened, and two public schools closed. The immediate cause of the Aliso Canyon blowout was a cracked well casing and lack of a shut-off valve. Federal standards to regulate underground gas storage were drafted in response to the Aliso Canyon leak. However, the current administration has delayed their implementation.

Liquefied natural gas (LNG) facilities consist of liquefaction plants, import/export terminals, tanker ships, regasification terminals, and inland storage equipment. All together, this capital-intensive equipment transforms methane vapor into liquid form through a cryogenic process that lowers the temperature of the gas to its condensation point (– 259° F) and then transports it to distant locations not serviced by pipelines. Chilling natural gas to its liquid state shrinks its volume by a factor of 600, allowing LNG to be exported overseas on massive tanker ships. LNG is sometimes used as vehicle fuel in, for example, long-haul trucks. LNG facilities encourage fracking by creating storage for the glut of gas that fracking has created, by enabling its export, and by driving up prices and profit margins.

LNG liquefaction requires immense energy in order to achieve the ultra-low temperatures required for condensation. An LNG facility typically requires its own power plant. Because they rely on evaporative cooling to maintain the liquid at super-chilled temperatures and prevent explosions, LNG tanks are leaky by design: vaporized gas is vented from storage tanks directly into the atmosphere. Larger tanks are engineered to capture boiled-off gas, but this process is not leak-proof. Before it is used or sent down a pipeline, LNG must be regasified via an energy-intensive process that requires massive infrastructure of its own, including periodic flaring to control pressure. Refrigeration, venting, leaks, flaring, and shipping make LNG more energy intensive than conventional natural gas. A new analysis shows that exporting large quantities of LNG from the United States will likely cause global greenhouse gas emissions to rise not only because of its energy penalty but also because LNG exports add more fossil fuels to the global market and extend the lifespan of U.S. coal-fired plants.

LNG creates acute public safety risks. LNG explodes when spilled into water and, if spilled on the ground, can turn into rapidly expanding, odorless clouds that can flash-freeze human flesh and asphyxiate by displacing oxygen. If ignited at the source, LNG vapors can become flaming "pool fires" that burn hotter than other fuels and cannot be extinguished. LNG fires burn hot enough to cause second-degree burns on exposed skin up to a mile away. LNG facilities pose significant risks to nearby population centers, and have been identified as potential terrorist targets.

<u>Sand mining and processing</u>

- November 25, 2017 – In Minnesota, a district judge upheld Winona County's ban on the mining, processing, and loading of frack sand. In her decision, the judge referenced public health and safety threats, fragility of the water quality in the area, and evidence for harm from sand mines in other areas. Winona is the first county in the United States to pass a countywide ban on frack sand extraction. Efforts to replicate the ban are now ongoing in neighboring counties.[797, 798]

- July 5, 2016 – The Wisconsin Department of Natural Resources (DNR) released a *Strategic Analysis for Public Review* of the state's industrial sand mining industry that downplayed environmental health effects from air pollution. There are 128 industrial sand mine facilities in Wisconsin, including the mines themselves and processing and rail loading facilities. The DNR identified airborne particulate matter as a primary concern for industrial sand mining facilities and said that air quality monitors in western Wisconsin have not detected a problem.[799] Researchers, organizations, and the native community involved in monitoring impacts of the frack sand industry challenged these findings, pointing to lack of data collection on the most dangerous kind of particulate matter called PM2.5, which represents fine particles that are less than 2.5 microns in width. These critics noted that the U.S. Environmental Protection Agency (EPA) had previously expressed concerns about the DNR's approach to regulating PM2.5.[800] Regarding groundwater, the report described elevated levels of several metals in wastewater holding ponds at the sand mines, presenting a risk to groundwater quality.

- March 25, 2016 – The Occupational Safety and Health Administration (OSHA) amended its existing standards for occupational exposure to respirable crystalline silica, "having determined that employees exposed to respirable crystalline silica at the previous permissible exposure limits face a significant risk of material impairment to their health."[801] Key provisions include the reduction of the permissible exposure limit to 50 micrograms per cubic meter of air, averaged over an 8-hour shift. The standards cover many industries with some having two years to comply; the hydraulic fracturing industry is allowed an additional five-year extension for engineering controls, until June 23, 2021.[802] The *New York Times* reported that safety experts have advocated for a tightening of silica exposure standards for the past forty years but that "progress was stymied for decades by resistance from affected companies and regulatory inaction." The article reported that many oil and gas companies in particular were not meeting the current silica

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797 McKinney, M. (2017, November 25). Judge's ruling on Winona County ban of frac sand mining stirs interest. *Minneapolis Star-Tribune.* Retrieved from http://www.startribune.com/judge-s-ruling-on-winona-county-frac-sand-ban-stirs-interest/459974433/

798 Rogers, C. (2017, November 22). District court upholds county frac sand ban. Winona Post. Retrieved from http://www.winonapost.com/Article/ArticleID/57056/District-court-upholds-county-frac-sand-ban

799 Wisconsin Department of Natural Resources. (2016). *Industrial sand mining in Wisconsin: Strategic analysis for public review.* Retrieved from http://dnr.wi.gov/topic/EIA/documents/ISMSA/ISMSA.pdf

800 Hubbuch, C. (2016, July 6). DNR releases frac sand analysis to immediate criticism from environmental group. *LaCrosse Tribune.* Retrieved from http://lacrossetribune.com/news/local/dnr-releases-frac-sand-analysis-to-immediate-criticism-from-environmental/article_bce8ea56-fff1-52ae-97cb-c67cfb120a1f.html

801 Occupational Safety and Health Administration. (2016, March 25). Occupational exposure to respirable crystalline silica. *Federal Register.* Retrieved from https://www.federalregister.gov/articles/2016/03/25/2016-04800/occupational-exposure-to-respirable-crystalline-silica

802 Occupational Safety and Health Administration. (2016, March 25). OSHA's Final Rule to protect workers from exposure to respirable crystalline silica. United States Department of Labor, Washington, DC. Retrieved from https://www.osha.gov/silica/

exposure standard. The new rules, when fully in effect, are estimated to save 600 lives and prevent 900 new cases of silicosis per year.[803]

- March 1, 2016 – University of Wisconsin anthropologist Thomas Pearson conducted in-depth interviews examining the impact of frack sand mining on sense of community, quality of life, and place in nearby residents. His findings indicated that the sudden influx of this heavy extractive industry has eroded residents' sense of place and belonging and that these experiences are rarely taken into account by policymakers. Residents report "significant anxiety and stress from truck traffic, noise, light pollution, and uncertainty about environmental health impacts," and distress caused by drastic changes to long-familiar landscapes over which they have no control. Pearson concluded that policymakers should pay closer attention to the uneven distribution of benefits and costs and "recognize that the costs go beyond quantifiable economic or environmental impacts."[804]

- January 29, 2016 – The Institute for Wisconsin's Health, Inc. released its Health Impact Assessment (HIA) on frack sand mining operations in western Wisconsin, prepared with the participation of 15 local and tribal health departments. According to the report, the HIA was a collaborative effort. The scope of the report was limited to the potential for community-level health effects of industrial sand mining in western Wisconsin. Regarding air quality, the report concluded that health effects from the impact of industrial sand mining on community-level air quality related to particulate matter are unlikely, and that it was also unlikely that community members would be exposed to respirable crystalline silica from industrial sand mining as currently regulated. Regarding water quality, the report concluded that contamination is possible; however, health effects were unlikely. Quality of life effects were likely, but variable.[805] Though it was a "Level 1 Partner" for the report, the Ho-Chunk Nation responded to the HIA with criticism, writing, "we are disappointed with the conclusions drawn in the report, particularly in the section on air quality impacts, and we believe a more robust assessment of the air quality impacts is required before such conclusions can be drawn." They wrote that the HIA failed to provide an accurate and complete analysis of the health threats posed by this industry because of the limited scope, and "minimal discussion about fine particulate matter (or PM2.5), which likely presents the biggest threat from industrial sand mining operations.[806] As reported by Rochester, Minnesota's *Post-Bulletin*, Crispin Pierce, director of University of Wisconsin-Eau Claire's environmental public health program, "believes the study ignored important air quality data collected by university students at

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[803] Meier, B. (2016, March 24). New rules aim to reduce silica exposure at work sites. *The New York Times.* Retrieved from http://www.nytimes.com/2016/03/24/business/new-rules-aim-to-reduce-silica-exposure-at-work-sites.html?_r=1

[804] Pearson, T. (2016). Frac sand mining and the disruption of place, landscape, and community in Wisconsin. *Human Organization*, *75*(1), 47-58. doi: http://dx.doi.org/10.17730/0018-7259-75.1.47

[805] Boerner, A., Young, N., & Young, D. (2016). *Health impact assessment of industrial sand mining in western Wisconsin.* Institute for Wisconsin's Health, Inc., Madison, WI. Retrieved from http://www.instituteforwihealth.org/uploads/1/2/7/8/12783470/iwhi_industrial_sand_w_covers.pdf

[806] Ho-Chunk Nation. (2016, March 9). *Concerns about air quality impacts and human health remain after release of industrial sand mining Health Impact Assessment* [Press release]. Retrieved from http://midwestadvocates.org/assets/resources/Frac%20Sand%20Mining/20160309HoChunkHIARelease.pdf

sand mining sites at Bloomer, New Auburn and Augusta during the past 18 months," which he described as "the only work that looked at these fine particles."[807]

- November 6, 2015 – According to findings from a pilot study led by Crispin Pierce (see entry above), levels of fine particulate matter (PM2.5) are not being adequately measured near frack sand operations. Air monitors set up by Pierce and his team consistently showed higher readings than detections measured by Wisconsin's DNR.[808] In some instances, PM2.5 levels exceeded the EPA guideline of 12 micrograms per cubic meter of air. In an accompanying news story, Pierce noted that the state's air quality data largely comes from industry itself. "'The DNR so far has continued to shy away from doing their own monitoring,' he said. 'The monitoring I've seen so far is inadequate. People aren't looking at PM2.5, and they really should be—from unbiased sources.'"[809]

- October 15, 2015 – *InsideClimate News* reported on the response of nearby communities to the "bust" cycle of the frack sand industry in Wisconsin and Minnesota. Reactions reported included ongoing concerns that the industry does not provide permanent economic prosperity. Municipalities and community organizations are using the lull to advance protections in advance of a possible upturn: "Towns in the region are also trying to strengthening their local zoning ordinances, such as adding rules to limit industrial noise and light pollution. In other cases, communities are trying to oust pro-sand advocates from office."[810]

- June 30, 2015 – Because the amount of sand used per fracking well has increased, demand for silica sand by the oil and gas industry is still growing even though new drilling activity has taken a downturn. A global investment bank reported that fracking operations now require an average of 4.2 million pounds of sand per well. A few years ago, silica sand comprised 9.5 percent of fracking fluid but now is closer to 20 percent. Further "rising intensity" of sand use is expected.[811]

- June 15, 2015 – An investigative report by *EnergyWire* documented self-reported health impacts among residents of southwestern Wisconsin who live near silica sand mining operations that service the fracking industry. Exposure to silica dust is a proven cause of silicosis and lung cancer. [See further entries on silica sand exposure among workers in the section, "Occupational Health and Safety Hazards."] Residents near frack sand mine

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807 Lindquist, E. (2016, February 4). Report downplays frac sand link to health troubles. *Post-Bulletin*. Retrieved from http://www.postbulletin.com/news/local/report-downplays-frac-sand-link-to-health-troubles/article_b3023c6c-fe74-5028-a7a4-6238fa035eaa.html

808 Pierce, C., Walters, K., Jacobson, J., & Kroening, Z. (2015.) PM2.5 Airborne Particulates near frac sand operations. *Journal of Environmental Health 78,* 8-12.

809 Schuessler, R. (2015, November 6). Wisconsin locals fear dust from mines for fracking sand even as boom wanes. *Aljazeera America.* Retrieved from http://america.aljazeera.com/articles/2015/11/6/wisconsin-locals-fear-frac-sand-mining.html

810 Hirji, Z. (2015, October 15). In fracking downturn, sand mining opponents not slowing down. *InsideClimate News*. Retrieved from http://insideclimatenews.org/news/14102015/fracking-struggles-sand-mining-opponents-momentum-Minnesota-Wisconsin

811 Chapa, S. (2015, June 30). Demand for sand: frac sand use per well goes up amid low oil prices. *San Antonio Business Journal*. Retrieved from http://www.bizjournals.com/sanantonio/blog/eagle-ford-shale-insight/2015/06/demand-for-sand-frac-sand-use-per-well-goes-up.html

operations reported exposure to dust pollution and respiratory problems. Air monitoring data from the Wisconsin DNR showed that none of the state's 63 active sand mines were in violation for particulate matter, but, as the author noted, the state measured particles only 10 micrometers in diameter or larger.[812] Below this diameter, crystalline silica particles are small enough to bypass the body's natural clearance mechanisms and are likely to lodge deep in the lungs where they can initiate scarring, autoimmune reactions, and tumor formation.[813]

Wastewater treatment facilities

- 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.[814] 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.[815]

Pipelines and compressor stations

- October 12, 2017 – Researchers at University of Albany's Institute for Health and the Environment prepared a 300-page technical report on the health effects of the emissions from 18 natural gas compressor stations in New York State. The team found that, collectively, these sites released 40 million pounds of 70 different contaminants over a seven-year period, making natural gas compressor stations the seventh largest point source of air pollution in the state. By volume, the largest emissions were nitrogen oxides, carbon monoxide, volatile organic compounds (VOCs), formaldehyde, and particulate matter. Exposure to these chemicals is linked to cancer, as well as cardiovascular, neurological, and developmental disorders. The authors noted, "The potential health impacts of the large volumes of pollutants generated by natural gas compressor stations have not been addressed, let alone answered, by those arguing for their construction and expansion."[816]

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[812] King, P. (2015, June 15). Frac sand towns question whether rules protect them against silica pollution. *EnergyWire*. Retrieved from http://www.eenews.net/stories/1060020192

[813] U.S. Department of Labor, Occupational Safety and Health Administration. (n.d.) Dust and its control. Retrieved from https://www.osha.gov/dsg/topics/silicacrystalline/dust/chapter_1.html

[814] Field, R. A., Soltis, J., McCarthy, M. C., Murphy, S., & Montague, D. C. (2015). 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,* 3527-3542. doi: 10.5194/acp-15-3527-2015

[815] Peterka, A. (2015, April 2). Study links Wyo. winter ozone to drillers' wastewater plant. *Greenwire*. Retrieved from http://www.eenews.net/stories/1060016205

[816] Russo, P. N., & Carpenter, D. O. (2017, October 12). *Health effects associated with stack chemical emissions from NYS natural gas compressor stations, 2008-2014.* Retrieved from https://www.albany.edu/about/assets/Complete_report.pdf

- October 11, 2017 – A study of airborne methane emissions from assorted components of natural gas infrastructure in California, including compressor stations and storage facilities, confirmed earlier studies in finding widely variable leakages. The results suggested that a significant fraction of the methane emitted from storage facilities may, in fact, be escaping from their associated compressor stations.[817]

- July 17, 2017 – A comprehensive investigation of the pipeline approval process by the Center for Public Integrity, *StateImpact Pennsylvania*, and National Public Radio found that the Federal Energy Regulatory Commission (FERC), which is charged with ensuring the public's interest, routinely assesses need based on company filings and functions as an agency captured by industry interests, concluding, "at every turn, the agency's process favors the pipeline companies." The result, according to this analysis of more than 500 pipeline cases, is that the financial interests of the gas industry, and not market demand or public necessity, is driving the ongoing pipeline build-out. In some cases, utility companies have complex financial ties to the pipeline companies that service them.[818] Continuing this investigation, *InsideClimate News* then reviewed several large, new pipeline proposals in the Marcellus and Utica Shale regions, focusing on joint ventures and interlocking financial relationships between customers (state-regulated utilities) and suppliers (pipeline companies). Affiliate agreements that allow parent companies of utilities to seek federal certificates for interstate pipelines—which typically allow a 14 percent return on equity—contribute to the ongoing frenzy of pipeline construction even when natural gas demand is flat. Existing pipelines, the investigation noted, run at only slightly more than half capacity.[819]

- July 12, 2017 – A Canadian study found that oil and gas infrastructure, including compressor stations, contributes to habit fragmentation and increases parasitism by cowbirds on Savannah sparrow nests in the Northern Great Plains. Populations of North American grassland songs birds, including the Savannah sparrow, are declining precipitously, mostly due to habitat loss and degradation. These results suggest that "brood parasitism associated with oil and natural gas infrastructure may result in additional pressures that reduce the productivity of this declining grassland songbird."[820]

- May 16, 2017 – An analysis of records from state agencies revealed that low-pressure flow lines at oil and gas well sites are responsible for more than 7,000 spills, leaks, and accidents since 2009. Flow lines carry oil, gas, or wastewater from scattered pieces of

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[817] Mehrotra, S., Faloona, I., Suard, M., Conley, S., & Fischer, M. L. (2017). Airborne methane emission measurements for selected oil and gas facilities across California. *Environmental Science & Technology 51*(21), 12981–12987. doi: 10.1021/acs.est.7b03254

[818] Lombardi, K., & Hopkins, J. S. (2017, July 17). Natural gas building boom fuels climate worries, enrages landowners. *NPR.org.* Retrieved from http://www.npr.org/2017/07/17/536708576/natural-gas-building-boom-fuels-climate-worries-enrages-landowners

[819] McKenna, P. (2007, August 3). Pipeline payday: how builders win big, whether more gas is needed or not. *InsideClimate News.* Retrieved fromhttps://insideclimatenews.org/news/02082017/natural-gas-pipeline-boom-corporate-profit-bubble-limited-demand-climate-emissions

[820] Bernath-Plaisted, J., Nenninger, H., & Koper, N. (2017). Conventional oil and natural gas infrastructure increases brown-headed cowbird (*Molothrus ater*) relative abundance and parasitism in mixed-grass prairie. *Royal Society Open Science, 4*(7), 170036. doi: 10.1098/rsos.170036

equipment within a production site. Other than in New Mexico, operators are not required to report gas leaks from flow lines. A fatal explosion in April 2017 in a Firestone, Colorado home built on top of an oil field was triggered when an abandoned flow line seeped gas into a basement where it ignited. Two people were killed and one was badly injured. Soon after, Colorado Governor John Hickenlooper ordered a statewide review of all oil and gas lines located near occupied buildings. Preliminary data showed that 16,000 wells across Colorado have flow lines that lie within 1,000 feet of homes. Corrosion is a leading cause of flow line failures.[821, 822]

- February 15, 2017 – A team of researchers from University of Texas investigated emissions from natural gas compressor stations throughout Pennsylvania and New York. They found that compressors emitted highly variable plumes of methane that spread downwind and were measurable a full mile away at levels that could expose nearby residents, especially during temperature inversions. The researchers concluded, "Our data indicate that compressor stations are likely sources of methane emissions and presumably co-emitted air contaminants, and can sporadically/episodically emit methane at relatively high levels…if such facilities are to be permitted to release specified amounts of contaminants, those amounts should be actively measured and verified. Without measurement there can be no assurance that permit conditions are being met."[823]

- November 30, 2016 – A CityLab investigation used data from the Pipeline and Hazardous Materials Safety Administration to map all significant U.S. pipeline accidents between 1986 and 2016 and concluded, "wherever pipelines are extended, deadly accidents will follow." Pipeline accidents over the past 30 years have resulted in 548 deaths, more than 2,500 injuries, and over $8.5 billion in damages. Accidents are particularly common in Texas and Louisiana.[824]

- July 5, 2016 – The National Energy Board, Canada's pipeline watchdog, gave two of Canada's largest pipeline companies six months to fix severe deficiencies in pipelines, ultimately issuing an emergency safety order in February 2016. Newly released federal documents showed that Texas-based Kinder Morgan and Alberta-based Enbridge were both looking into the use of defective parts purchased from Thailand-based Canadoil Asia that recently went bankrupt. U.S. regulators warned of these deficiencies eight years prior. At least one Canadian pipeline with defective materials exploded during that period.[825]

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[821] Soraghan, M. (2017, May 16). Flow lines cited in more than 7K spills. *E&E News.* Retrieved from https://www.eenews.net/stories/1060054568
[822] Lee, M. (2017, June 12). Fatal explosion threatens more upheaval over drilling in Colo. *E&E News.* Retrieved from https://www.eenews.net/stories/1060055846
[823] Payne, B. F., Ackley, R., Wickler, A. P., Hildenbrand, Z., Carlton, Jr., D. D., & Schug, K. A. (2017). Characterization of methane plumes downwind of natural gas compressor stations in Pennsylvania and New York. *Science of the Total Environment, 580*, 1214-21. doi: 10.1016/j.scitotenv.2016.12.082
[824] Joseph, G. (2016, November 30). 30 years of oil and gas pipeline accidents, mapped. *CityLab.* Retrieved from https://www.citylab.com/environment/2016/11/30-years-of-pipeline-accidents-mapped/509066/
[825] De Souza, M. (2016, July 5). How Canada's pipeline watchdog secretly discusses 'ticking time bombs' with industry. *National Observer.* Retrieved from http://www.nationalobserver.com/2016/07/05/news/how-canada%E2%80%99s-pipeline-watchdog-secretly-discusses-ticking-time-bombs-industry

- June 10, 2016 – EPA Region 2 submitted comments to FERC on Docket Nos. PFI6-3, Eastern System Upgrade Project, which includes new natural gas compressor stations in Hancock and Highland, New York. The EPA submission suggested an analysis of whether this project was needed; clarification of what is meant by a loop system; evaluation of alternatives; a comprehensive analysis of cumulative, indirect, and secondary impacts; information on greenhouse gas emissions and climate change impacts; a Health Impact Assessment; the inclusion of all pollution prevention practices; and a consideration of environmental justice concerns.[826] The company agreed to provide funding toward a health study but wished to retain the ability to determine the study parameters.[827] Skeptical of the health study's funding and parameters, residents and potentially impacted towns objected to the company's dismissal of the towns' laws prohibiting the construction and operation of heavy industrial use facilities. The Deputy Supervisor of one of the affected towns "said he was encouraged by the federal Environmental Protection Agency's comments on the project's preliminary federal application. He said the EPA concerns were 'the same as ours.'"[828]

- April 27, 2016 – In its report on two natural gas pipeline expansion projects in Appalachia, the Institute for Energy Economics and Financial Analysis demonstrated that the Atlantic Coast and Mountain Valley pipelines are "emblematic of the risks that such expansion creates for ratepayers, investors and landowners." The report concluded that pipelines out of the Marcellus and Utica region are being overbuilt, putting ratepayers at risk of paying for excess capacity, landowners at risk of losing their property to unnecessary projects, and investors at risk of loss. The report stated that FERC facilitates this building of excess pipeline capacity and its approach for assessing need is insufficient.[829]

- April 22, 2016 – The federal Agency for Toxic Substances and Disease Registry (ATSDR) released a report on air quality near a natural gas compressor station in Brooklyn Township, Susquehanna County, Pennsylvania, finding levels of fine particulate matter (PM2.5) at levels that can damage human health in those with long-term exposure. Evaluating data from an 18-day EPA field air monitoring event, the report found that the average ambient 24-hour PM2.5 concentration observed at one residence (19 µg/m3) was higher than the nearest regional National Ambient Air Quality Standards (NAAQS) monitoring station (12.3 µg/m3) in Scranton, PA, over the same period. ATSDR concluded that there was evidence that long-term exposure to PM2.5 at the levels found can cause an increase in mortality, respiratory problems, hospitalizations, preterm births, and low birth weight. The agency said that in the short term, exposure

[826] EPA Region 2. (2016, June 10). Docket Nos. PFI6-3, Eastern System Upgrade Project (comments). Retrieved from https://elibrary.ferc.gov/idmws/file_list.asp?document_id=14468753
[827] Mayer, F. (2016, April 27). Millennium to pay for health study. *River Reporter.* Retrieved from http://www.riverreporter.com/news/4302/2016/04/27/millennium-pay-health-study
[828] Julse, D. (2016, June 22). Highland concerned about study underfunding. *River Reporter.* Retrieved from http://www.riverreporter.com/news/4302/2016/06/22/highland-concerned-about-study-underfunding
[829] Kunkel, C., & Sanzillo, T. (2016). *Risks associated with natural gas pipeline expansion in Appalachia.* The Institute for Energy Economics and Financial Analysis. Retrieved from http://ieefa.org/wp-content/uploads/2016/04/Risks-Associated-With-Natural-Gas-Pipeline-Expansion-in-Appalachia-_April-2016.pdf

could be harmful to sensitive populations, such as those with respiratory problems or heart disease. The agency recommended that sensitive individuals monitor air quality and limit activity accordingly, and that the PA DEP work to reduce other sources of PM and its precursors.[830]

- April 3, 2016 – The Southwest Pennsylvania Environmental Health Project issued a *Technical Report* in response to the January 29, 2016 federal ATSDR report on the Brigich compressor station in Chartiers Township, Washington County, Pennsylvania. ATSDR detected chemicals that had been reported at gas sites previously, and this confirmation of their presence provided "an important acknowledgement that neighbors of such facilities are being exposed (often at very close range) to chemicals that bring with them the possibility of short- and long-term health effects." The report stated that, in conjunction with the monitoring work of the EPA, ATSDR "provided a solid set of data." However, due to the limitations of the methodologies available to them, the authors were "concerned that there was, in the end, an underestimate of risk to community members."[831]

- April 1, 2016 – Kinder Morgan, the largest energy infrastructure company in North America, suspended construction of a $1 billion pipeline project that would have carried gasoline and diesel fuel across the southeastern United States. Construction was suspended after landowners protested the seizure of their property, a Georgia Superior Court judge upheld a decision denying a certificate that would have allowed the company to use eminent domain, and the state legislature passed legislation to block the property seizure.[832]

- March 26, 2016 – According to a Boston University-led study, fugitive emissions from urban natural gas pipeline systems were the largest anthropogenic source of the greenhouse gas methane in the United States and contribute to the risk of explosions in urban environments, with 15 percent of leaks qualifying as potentially explosive.[833] "All leaks must be addressed, as even small leaks cannot be disregarded as 'safely leaking,'" concluded the report authors. In an interview with *InsideClimate News*, the lead author said that in addition to weighing the safety risks from gas leaks, regulators and utility

[830] Agency for Toxic Substances and Disease Registry. (2016, April 22). *Health Consultation: Brooklyn Township PM2.5, Brooklyn Township, Susquehanna County, Pennsylvania.* U.S. Department of Health and Human Services, Atlanta, GA. Retrieved from http://www.atsdr.cdc.gov/HAC/pha/BrooklynTownship/BrooklynTwnsp_pm2-5_HC_Final_04-22-2016_508.pdf
[831] Southwest Pennsylvania Environmental Health Project. (2016, April 3). ATSDR releases investigation of Pennsylvania compressor station. *Response to Governmental Action and Publication*, *1*. Retrieved from http://www.environmentalhealthproject.org/resources/research-factsheets
[832] McKenna, P. (2016, April 1). Property rights outcry stops billion-dollar pipeline project in Georgia. *InsideClimate News.* Retrieved from https://insideclimatenews.org/news/01042016/palmetto-pipeline-kinder-morgan-georgia-eminent-domain-oil-gas-republicans
[833] Hendrick, M. F., Ackley, R., Sanaie-Movahed, B., Tang, X., & Phillips, N.G. (2016). Fugitive methane emissions from leak-prone natural gas distribution infrastructure in urban environments. *Environmental Pollution, 213,* 710–716. doi:10.1016/j.envpol.2016.01.094

companies must also consider the climate impact of leaks when determining priorities for repairing and replacing pipes.[834]

- March 7, 2016 – A lawsuit filed against FERC in U.S. District Court in Washington, D.C challenged the agency's relationship with industry, reported *Penn Live*: "The suit accuses the commission of regulatory capture, a situation in which corporations control regulators." FERC receives all of its funding from the energy companies that it regulates and had never rejected a pipeline plan, which, according to the complainant, demonstrates "clear bias and corruption."[835]

- February 26, 2016 – Congressman Chris Gibson (NY-19), in response to citizen concerns, sent a letter to FERC regarding the proposed 41,000-horsepower compressor station in southern Rensselaer County, New York, part of the Northeast Energy Direct (NED) pipeline project. He discussed the inadequacy of federal exposure standards with regard to exposures at compressor sites and lack of medical expertise in these decisions. He requested public health expertise on all Environmental Assessment and Environmental Impact Statement teams, an independent panel to review the federal exposure standards around compressor stations, and "a transparent and effective review process."[836] His call was supported by other elected officials, as well as public health researcher David O. Carpenter, MD, who has studied compressor station pollutants.[837]

- January 29, 2016 – ATSDR, in collaboration with the EPA Region 3 Air Protection Division, conducted an exposure investigation to evaluate exposures of residents living near the Brigich natural gas compressor station in Chartiers Township, Washington County, Pennsylvania. ATSDR concluded that, although exposure to the levels of chemicals detected in the ambient air was not expected to harm the health of the general population, "some sensitive subpopulations (e.g., asthmatics, elderly) may experience harmful effects from exposures to hydrogen sulfide and PM 2.5 [and] [s]ome individuals may also be sensitive to aldehyde exposures, including glutaraldehyde." According to ATSDR, one of the study's limitations was that the sampling "may not have adequately captured uncommon but significant incidents when peak emissions (e.g. unscheduled facility incidents, blowdowns or flaring events) coincide with unfavorable meteorological conditions (e.g. air inversion)." ATSDR recommendations included reducing exposures to the chemicals of concern to protect sensitive populations, continued collection of

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834 McKenna, P. (2016, March 31). Methane hazard lurks in Boston's aging, leaking gas pipes, study says. *InsideClimate News.* Retrieved from https://insideclimatenews.org/news/30032016/boston-natural-gas-pipelines-leaking-methane-climate-change-explosion

835 Pynes, M. (2016, March 7). Federal agency funded by energy industry has never rejected a pipeline plan. *PennLive.com.* Retrieved from http://www.pennlive.com/news/2016/03/pipeline_fights_raise_big_ques.html#incart_article_small

836 Gibson, C. (2016, February 26). Compressor station needs review. *Sullivan County Democrat.* Retrieved from http://scdemocratonline.com/webpages/letterdetail.aspx?id=9f047d33-ba32-4027-883b-ff2e457ebb7a

837 Nearing, B. (2016, March 31). Gibson: Federal natural gas air pollution safety standards may be obsolete. *Albany Times Union*. Retrieved from http://www.timesunion.com/business/article/Gibson-Federal-natural-gas-air-pollution-safety-7221271.php

emissions data for long-term and peak exposures, and air modeling to better understand ambient air quality.[838]

- December 8, 2015 – The Niagara County Legislature, following the recommendations of the Medical Society of the State of New York, called for a Health Impact Assessment (HIA) on natural gas infrastructure, including compressor stations, and co-hosted a conference in Albany on the Medical Society's health findings. A compressor station with twin compressors, part of the "2016 Northern Access Plan" to transfer gas from Pennsylvania to Canada, is proposed for the county.[839]

- November 9, 2015 – Following the 2010 heavy oil spill in Michigan's Kalamazoo River, Congress ordered an audit that spotlighted the industry's poor record of spotting leaks. *Politico* reported on the 2015 regulatory structure ultimately unveiled in response, determining the proposal "fails to patch that hole in the nation's pipeline safety net." "While the agency's proposed rule expands the number of pipelines that must have a leak-detection system in place, it sets no basic standards for how well that technology should work. Instead, safety advocates say, it lets pipeline operators decide for themselves whether they are adequately prepared."[840]

- October 16, 2015 – The EPA urged FERC to consider "whether the Northeast Energy Direct pipeline could be combined with other projects, rather than constructing a new system that would have a host of environmental impacts," reported Oneonta, New York's *Daily Star*. The EPA also advised "that the gas demand addressed by NED's application could be met by renewable forms of energy such as solar and wind power…"[841] (Note: Kinder Morgan withdrew its NED pipeline application in April 2016.)

- September 17, 2015 – At a shale gas conference, industry representatives espoused the construction of new pipelines as necessary to re-invigorate the gas industry in the Marcellus. Speakers noted that FERC approval can be expected to now take longer, by about six months, blaming environmental groups for the delays.[842]

- September 9, 2015 – New pipelines are failing at a rate on par with gas transmission lines installed before the 1940s, according to an analysis of federal data by the Pipeline Safety

[838] Agency for Toxic Substances and Disease Registry. (2016, January 29). *Health Consultation: Exposure Investigation, Natural Gas Ambient Air Quality Monitoring Initiative Brigich Compressor Station, Chartiers Township, Washington County, Pennsylvania.* Retrieved from http://www.atsdr.cdc.gov/HAC/pha/Brigich_Compressor_Station/Brigich_Compressor_Station_EI_HC_01-29-2016_508.pdf

[839] Staff. (2015, December 8). County lawmakers call for study on compressor health risks. *Lockport Union-Sun & Journal.* Retrieved from http://www.lockportjournal.com/news/local_news/county-lawmakers-call-for-study-on-compressor-health-risks/article_932989cd-058a-594f-9ef2-e52827db85a6.html

[840] Schor, E. (2015, November 9). The hole in Obama's pipeline safety plan. *Politico.* Retrieved from http://www.politico.com/story/2015/11/obama-pipeline-safety-plan-oil-215617

[841] Mahoney, J. (2015, October 16). EPA: Can local pipeline plans merge? *Daily Star.* Retrieved from http://www.thedailystar.com/news/local_news/epa-can-local-pipeline-plans-merge/article_f2836510-a96b-5c2d-9892-755b94b1f640.html?mode=jqm

[842] Packel, D. (2015, September 17). Energy honchos lament FERC pipeline approval delays. *Law 360.* Retrieved from http://www.law360.com/publicpolicy/articles/697120/energy-honchos-lament-ferc-pipeline-approval-delays

Trust, reported by *S&P Global Market Intelligence*. "The gas transmission lines installed in the 2010s had an annual average incident rate of 6.64 per 10,000 miles over the time frame considered, even exceeding that of the pre-1940s pipes. Those installed prior to 1940 or at unknown dates had an incident rate of 6.08 per 10,000 miles." The director of the National Transportation Safety Board's Office of Railroad, Pipeline and Hazardous Materials Investigations "agreed that the rapid construction of pipelines in the U.S. is likely a contributing factor."[843]

- August 18, 2015 – Houston Advanced Research Center (HARC) scientists addressed "the commonly acknowledged sources of uncertainty which are the lack of sustained monitoring of ambient concentrations of pollutants associated with gas mining, poor quantification of their emissions, and inability to correlate health symptoms with specific emission events." They concluded that "more contemporary monitoring and data analysis techniques should take the place of older methods to better protect the health of nearby residents and maintain the integrity of the surrounding environment." "Real-time mobile monitoring, microscale modeling and source attribution, and real-time broadcasting of air quality and human health data over the World Wide Web" have been demonstrated, they wrote, by past, current, and planned future monitoring studies in the Barnett and Eagle Ford shale regions.[844] Founded as a technology incubator in 1982 by Houston oilman George P. Mitchell, HARC later re-aligned to focus on sustainable development.

- August 14, 2015 – HARC scientists found that port operations involving petrochemicals may significantly increase emissions of air toxics, including peaks of carcinogenic benzene of up to 37 ppb. The scientists matched the benzene spikes with pipeline systems. The spikes were at levels much higher than those reported in the EPA's 2011 National Emissions Inventory. The authors recommended the use of updated methods for ambient monitoring.[845] Lead scientist Jay Olaguer said in a related interview that "government regulators should wake up to the reality of the situation, that their methods of tracking air pollution need to be updated so that the samples are taken in real time and can catch it when toxic vapors of this magnitude are released."[846]

- July 15, 2015 – Rensselaer County lawmakers passed a resolution asking the state of New York to freeze the approval process for the Northeast Energy Direct pipeline—

[843] Smith, S. (2015, September 9). As US rushes to build gas lines, failure rate of new pipes has spiked. *SNL Financial.* Retrieved from https://www.snl.com/InteractiveX/Article.aspx?cdid=A-33791090-11060

[844] Olaguer, E. P., Erickson, M., Wijesinghe, A., Neish, B., Williams, J., & Colvin, J. (2015). Updated methods for assessing the impacts of nearby gas drilling and production on neighborhood air quality and human health. *Journal of the Air & Waste Management Association, 66*, (2), 173-183. doi: 10.1080/10962247.2015.1083914

[845] Olaguer, E. P., Erickson, M. H., Wijesinghe, A., & Neish, B. S. (2015). Source attribution and quantification of benzene event emissions in a Houston ship channel community based on real-time mobile monitoring of ambient air. *Journal of the Air & Waste Management Association, 66*, (2), 164-172. doi: 10.1080/10962247.2015.1081652

[846] Wray, D. (2016, February 23). Scientists discover pipelines belching benzene in East Houston. *Houston Press.* Retrieved from http://www.houstonpress.com/news/scientists-discover-pipelines-belching-benzene-in-east-houston-8181569

which would carry fracked gas from Pennsylvania to Boston—until it conducts a comprehensive health impact assessment for natural gas pipelines.[847]

- July 8, 2015 – Researchers from West Virginia University completed leak and loss audits for methane emissions at three natural gas compressor stations and two natural gas storage facilities, with a "leak" defined as an unintended release of natural gas due to malfunction of a component, and a "loss" defined as an intended release of natural gas. In terms of frequency, most emissions were leaks, but on a mass basis, losses were the dominant source of methane emissions (88 percent). The top loss emitters were engine exhausts (accounting for nearly half), packing vents, and slop tanks. Emissions from compressor blowdowns were not included.[848] A related study by a University of Houston team found that emission rates from compressor stations in Texas' Barnett Shale were far higher than from well pads.[849, 850]

- July 7, 2015 – Seeking a method to bridge the gap between bottom-up and top-down methods of measuring methane emissions, Purdue University, University of Houston, the National Oceanic and Atmospheric Administration (NOAA), Environmental Defense Fund, and independent researchers surveyed eight high-emitting point sources in the Barnett Shale using an aircraft-based "mass balance" approach. Results from four gas processing plants and one compressor station highlighted the importance of addressing methane "super-emitters" and confirmed that self-reports from the Greenhouse Gas Reporting Program underestimated actual emission rates by a factor of 3.8 or higher, due to "underestimated facility emissions, temporal variability of emissions, and the exclusion of nonreporting facility emissions."[851]

- July 7, 2015 – Using relatively easy-to-acquire and inexpensive stable isotopic and alkane ratio tracers, researchers are now able to distinguish methane arising from natural gas production and transport from agricultural and urban methane sources, and, in addition, to distinguish between methane released from shale gas as opposed to conventional wells. Initial research from the University of Cincinnati, University of California at Irvine, and the Environmental Defense Fund found that methane in the Barnett Shale hydraulic fracturing region near Fort Worth, Texas, represents a complex mixture of these sources. This new approach, used for ground-level measurements, can complement and extend top-down approaches, allowing for more accurate inventories

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[847] Nearing, B. (2015, July 15). County: Put study before any permit. *Albany Times-Union.* Retrieved from http://www.timesunion.com/news/article/County-Put-study-before-any-permit-6387404.php

[848] Johnson, D. R., Covington, A. N., & Clark, N. N. (2015). Methane emissions from leak and loss audits of natural gas compressor stations and storage facilities. *Environmental Science & Technology, 49,* 8132-8138. doi: 10.1021/es506163m

[849] Lan, X., Talbot, R., Laine, P., & Torres, A. (2015). Characterizing fugitive methane emissions in the Barnett Shale area using a mobile laboratory. *Environmental Science & Technology, 49*, 8139-8146. doi: 10.1021/es5063055

[850] Song, L., & Hirji, Z. (2015, July 8). Methane emissions in Texas fracking region 50 percent higher than EPA estimates. *InsideClimate News.* Retrieved from http://insideclimatenews.org/news/08072015/methane-emissions-texas-fracking-region-50-higher-epa-estimates-oil-gas-drilling-barnett-shale-environmental-defense-fund

[851] Lavoie, T. N., Shepson, P. B., Cambaliza, M. O. L., Stirm, B. H., Karion, A., Sweeney, C., . . . Lyon, D. (2015). Aircraft-based measurements of point source methane emissions in the Barnett Shale Basin. *Environmental Science & Technology*, *49,* 7904−7913. doi: 10.1021/acs.est.5b00410

of thermogenic and biogenic sources of methane emissions.[852]

- July 1, 2015 – In New York State, Schoharie County supervisors and medical professionals demanded comprehensive health impact assessments as a precondition for permitting natural gas pipelines and compressor stations.[853]

- June 12, 2015 – The Agency for Toxic Substances and Disease Registry investigated the health effects of ruptured gas pipelines in an analysis of data in a database on acute petroleum-related releases to which seven states contribute (Louisiana, New York, North Carolina, Oregon, Tennessee, Utah, and Wisconsin). From 2010 to 2012, there were 1,369 such incidents, which resulted in 259 injuries. More than three-quarters of these incidents were related to natural gas distribution. Equipment failure accounted for half of all incidents; human error accounted for 40 percent. The report noted the "continuing occurrence" of petroleum release incidents—including from natural gas pipeline ruptures—which have "the potential to cause mass casualties and environmental contamination."[854]

- June 9, 2015 – The American Medical Association (AMA) adopted a resolution, "Protecting Public Health from Natural Gas Infrastructure," that was based on a resolution adopted by the Medical Society of the State of New York. (See below.) The resolution states, "Our AMA recognizes the potential impact on human health associated with natural gas infrastructure and supports legislation that would require a comprehensive Health Impact Assessment regarding the health risks that may be associated with natural gas pipelines."[855]

- May 2, 2015 – The Medical Society of the State of New York adopted a resolution, "Protecting Public Health from Natural Gas Infrastructure," that recognizes the potential impact to human health and the environment of natural gas pipelines and calls for a governmental assessment of these risks.[856]

- March 3, 2015 – Researchers with the Southwest Pennsylvania Environmental Health Project measured ambient levels of particulate and volatile air pollutants from fracking-related operations and calculated expected human exposures in Washington County, Pennsylvania. Extremely high exposures peaked at night when air was still. These

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[852] Townsend-Small, A., Marrero, J. E., Lyon, D. R., Simpson, I. J., Meinardi, S., & Blake, D.R. (2015). Integrating source apportionment tracers into a bottom-up inventory of methane emissions in the Barnett Shale hydraulic fracturing region. *Environmental Science & Technology*, *49*, 8175‒8182. doi: 10.1021/acs.est.5b00057
[853] Adams, K. (2015, July 1). Schoharie County officials ask new studies on gas lines: Report say dangers are equivalent to fracking. *Daily Gazette*, Retrieved from http://www.dailygazette.com/news/2015/jul/01/0701_gasline/?print
[854] Anderson, A. R. (2015, June 12). Health effects of cut gas lines and other petroleum product release incidents—seven states. *Morbidity and Mortality Weekly Report*, *64*, 601-605.
[855] American Medical Association. (2015). H-135.930 Protecting public health from natural gas infrastructure, Resolution 519, A-15. Retrieved from https://www.ama-assn.org/sites/default/files/media-browser/public/hod/a15-hod-resolutions.pdf
[856] Medical Society of the State of New York. (2015). 2015 House of Delegates Actions: Public Health and Education. Retrieved from http://www.mssny.org/Documents/HOD/Actions/ActionPHE.pdf

fluctuating exposure events mimic, in frequency and intensity, the episodic nature of health complaints among residents. Over a one-year period, compressor stations were responsible for more extreme exposure events (118) than well pads or gas processing plants.[857]

- February 24, 2015 – As part of a literature review on the health impacts of compressor stations, the Southwest Pennsylvania Environmental Health Project reported that peak emissions of fine particles tended to occur during construction time, that day-to-day emissions during operational time can fluctuate greatly, and that a compressor blowdown typically represented the single largest emission event during operations. Hence, documentation of these fluctuations cannot be captured by calculating yearly averages. A blowdown is an intentional or accidental release of gas through the blowdown valve that creates a 30- to 60-meter-high gas plume. Blowdowns, which are used to control pressure, can last as long as three hours. The authors noted that blowdowns result in times of high levels of contaminant release and that anecdotal accounts associate blowdowns with burning eyes and throat, skin irritation, and headache.[858] There is neither a national or state inventory of compressor station accidents nor a body of peer-reviewed research on the public health impacts of compressor stations.

- February 17, 2015 – A Boston study found that emissions from residential, end-use natural gas infrastructure was a significant source of atmospheric methane—two to three times larger than previously presumed—and accounted for 60 to 100 percent of methane, depending on the season. Of all the natural gas in the downstream component of the natural gas system, 2.7 percent was lost to the atmosphere.[859]

- February 10, 2015 – A team of engineers from Pennsylvania and Colorado examined methane emissions from natural gas compressor stations and found that vents, valves, engine exhaust, and equipment leaks were also major emissions sources. There was considerable variation in emissions among the 45 compressor stations measured. Surprisingly, substantial emissions were found even when compressors were not operating.[860]

- December 27, 2014 – A *Pittsburgh Tribune-Review* investigation found that the vast majority of natural gas "gathering lines"—pipelines that take natural gas from rural well

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[857] Brown, D. R., Lewis, C., & Weinberger, B. I. (2015). Human exposure to unconventional natural gas development: a public health demonstration of periodic high exposure to chemical mixtures in ambient air. *Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances and Environmental Engineering, 50,* 460-72. doi: 10.1080/10934529.2015.992663

[858] Southwest Pennsylvania Environmental Health Project (2015, February 24). Summary on compressor stations and health impacts. Retrieved from http://www.environmentalhealthproject.org/wp-content/uploads/2012/03/Compressor-station-emissions-and-health-impacts-02.24.2015.pdf

[859] McKain, K., Down, A., Raciti, S. M., Budney, J., Hutyra, L. R., Floerchinger, C., . . . Wofsy, S.C. (2015). Methane emissions from natural gas infrastructure and use in the urban region of Boston, Massachusetts. *Proceedings of the National Academy of Sciences, 112,* 1941-46. doi: 10.1073/pnas.1416261112

[860] Subramanian, R., Williams, L. L., Vaughn, T. L., Zimmerle, D., Roscioli, J. R., Herndon, S. C., . . . Robinson, A.L. (2015). Methane emissions from natural gas compressor stations in the transmission and storage sector: measurements and comparisons with the EPA Greenhouse Gas Reporting Program protocol. *Environmental Science & Technology, 49,* 3252-61. doi: 10.1021/es5060258

pads to processing plants—were regulated by neither federal nor state pipeline safety laws. The United States has nearly 230,000 miles of natural gas gathering lines that are unregulated, operating without safety standards or inspection. These pipelines are among the largest and highest-pressure pipes in use and carry gas at nearly three times the pressure of transmission lines, which transport the gas from the processing plants to urban distribution networks.[861]

- November 11, 2014 – An analysis by a Carnegie Mellon University research team of 40,000 pipeline accidents from 1968 to 2009 found that comparatively few accidents accounted for a large share of total property damage, whereas a large share of fatalities and injuries were caused by numerous, small-scale accidents. There are 2.4 million miles of natural gas pipeline in the United States and 175,000 miles of hazardous liquid pipeline (which includes crude oil).[862]

- October 30, 2014 – A research team led by David O. Carpenter at University at Albany found high levels of formaldehyde near 14 compressor stations in three states. In Arkansas, Pennsylvania, and Wyoming, formaldehyde levels near compressor stations exceeded health-based risk levels. The authors noted that compressor stations can produce formaldehyde through at least two routes: it is created as an incomplete combustion byproduct from the gas-fired engines used in compressor stations. It is also created when fugitive methane, which escapes from compressor stations, is in the presence of sunlight. Formaldehyde is a known human carcinogen. Other hazardous air pollutants detected near compressor stations in this study were benzene and hexane. One air sample collected near a compressor station in Arkansas contained 17 different volatile compounds. (See entry for October 30, 2014 in Air Pollution.)

- October 15, 2014 – In comments to FERC, New York's Madison County Health Department reviewed the literature on compressor station emissions and expressed concerns about associated health impacts, including documented correlations between health problems and residential proximity to compressor stations. It also reviewed health outcomes associated with exposures to chemicals known to be released from compressor stations, including VOCs, carbonyls and aldehydes, aromatics, and particulate matter. In addition, gas from fracking operations transiting through compressor stations may carry gaseous radon. The Health Department noted a troubling lack of information on the intensity, frequency, and duration of emission peaks that occur during the blowdowns and large venting episodes that are a normal part of compressor operations.[863]

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[861] Wereschlagin, M. (2015, December 27). Rural gas gathering pipelines kindle concerns about safety laws. *Pittsburgh Review-Tribune*. Retrieved from http://triblive.com/news/editorspicks/7362085-74/lines-gas-safety#axzz3NAHfzYF8

[862] Siler-Evans, K., Hanson, A., Sunday, C., Leonard, N., & Tumminello, M. (2014). Analysis of pipeline accidents in the United States from 1968 to 2009. *International Journal of Critical Infrastructure Protection, 7,* 257-69. doi: 10.1016/j.ijcip.2014.09.002

[863] New York State Madison County Health Department (2014, October 15). Comments to the Federal Energy Regulatory Committee concerning docket no. CP14-497-000, Dominion Transmission, Inc. Retrieved from https://www.madisoncounty.ny.gov/sites/default/files/publicinformation/madison_county_doh_comments_-_docket_no._cp14-497-000.pdf

- September 16, 2014 – Noting the proximity of a proposed high-pressure pipeline to Indian Point Nuclear Facility, as well as the evidence linking compressor station emissions to negative health impacts, New York's Rockland County legislature adopted a resolution calling for a comprehensive Health Impact Assessment in regards to Spectra Energy's planned Algonquin Incremental Market (AIM) natural gas pipeline, compressor, and metering stations expansion project.[864] This resolution follows on the heels of similar resolutions expressing health concerns about the AIM project from both Westchester and Putnam County legislatures.[865, 866]

- January 24, 2013 – A report prepared for the Clean Air Council by an independent consulting firm to evaluate air quality impacts from the Barto Compressor Station in Penn Township, Lycoming County, Pennsylvania predicted "large exceedances" of the nitrogen dioxide (NO_2) 1-hour NAAQS. Researchers used allowable emissions in the PA DEP permit, the 2006-2010 meteorological data and the latest EPA modeling guidance for the model's prediction. Three techniques were used, and for two of the techniques, NAAQS exceedances occurred within a mile of the plant. The report concluded, "NO_2 impacts from the Barto plant alone are very significant since its emissions cause large exceedances of the 1-hour NAAQS."[867]

- July 13, 2011 – A Fort Worth air quality study assessed the impact of drilling and fracking operations, and ancillary infrastructure, on concentrations of toxic air pollutants in the city of Fort Worth, Texas. The study found that compressor stations were a significant source of fracking-related air pollution. The compressor engines were responsible for over 99 percent of the hazardous air pollutants emitted from compressor stations, of which 67 percent was formaldehyde.[868]

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[864] Rockland County Legislature. (2014, September 16). *Resolution No. 404 of 2014 urging that health, safety and planning concerns be addressed and mitigated in the Environmental Review and all other review processes before project permissions be granted for Spectra Energy's Algonquin Incremental Market (AIM) Natural Gas Pipeline, Compressor and Metering Stations Expansion Project.* Retrieved from https://sape2016.files.wordpress.com/2014/05/rockland-aim-resolution.pdf

[865] Board of Legislators County of Westchester, State of New York. (2014, July 21). *Resolution RES-2014-80 Algonquin Incremental Marketing Project resolution.* Retrieved from https://sape2016.files.wordpress.com/2014/05/080414-wcbol-resolution-no-80-2014-requesting-due-diligence-on-environment-p.pdf

[866] Putnam County Legislature. (2014, May 9). *Resolution #104, Resolution regarding the Algonquin Incremental Market (AIM) Project.* Retrieved from https://sape2016.files.wordpress.com/2014/05/putnam-county-resolutions-104-163-and-182-1.pdf

[867] Tran, K. T. (2013, January 24). *AERMOD modeling of NO2 impacts of the Barto Compressor Station: Final report.* Prepared for the Clean Air Council, Philadelphia, PA. Retrieved from http://www.pennfuture.org/UserFiles/File/MineDrill/Marcellus/CAC_EmissionsNO2_CompressorBarto_20130124.pdf

[868] Eastern Research Group. (2011, July 13). City of Forth Worth natural gas air quality study, final report. Retrieved from http://www.shaledigest.com/documents/2011/Air%20Quality%20Studies/Ft%20Worth%20Natural%20Gas%20Air%20Quality%20Study%20Final%20Report%20ERG%20Research%207-13-2011r.pdf. See also Energy Research Group. (2011, July 19). Forth Worth natural gas air quality study final report, pubic meeting presentation. Retrieved from http://fortworthtexas.gov/uploadedFiles/Gas_Wells/110719_ERG.pdf?v=110725

Gas storage: The Aliso Canyon leak

- November 22, 2017 – The U.S. Government Accountability Office (GAO) reported that, two years after the Aliso Canyon blow-out, the Pipeline and Hazardous Materials Safety Administration is failing to inspect natural gas storage sites in a timely manner, as called for by the Department of Transportation's interim standards. Until 2016, states set the standards for 211 of the nation's 415 gas storage sites, while the 204 sites that were connected to interstate pipelines had no standards at all. Collectively, these 415 natural gas storage sites contain about 17,000 wells that inject or withdraw natural gas from the underground formations below, which include depleted oil and gas reservoirs, abandoned mines, depleted aquifers, and hard rock caverns. The GAO noted that more than 300 cities and towns are located near natural gas storage sites.[869]

- June 21, 2017 – In response to requests from the oil and natural gas industry, the White House announced that it will delay implementation of a rule that would have set national standards for underground natural gas storage. Prompted by the 2015 disaster at Aliso Canyon and developed under the previous administration, this federal interim rule had called for phasing out single-point-of-failure, single-containment designs of the type that made impossible the task of swiftly shutting off the impaired Aliso Canyon well once it began leaking.[870]

- May 24, 2017 – A national assessment of thousands of underground gas storage wells by a Harvard School of Public Health team found that more than 20 percent are similar in design to the well that failed at Aliso Canyon. These obsolete wells, with single failure points and a median age of 74 years, operate in 19 states and represent more than half of the working capacity for U.S. natural gas. More than 2,700 of these wells were not originally designed to hold gas and, as at Aliso Canyon, have been repurposed to do so. An estimated 210 of these repurposed wells (located in Pennsylvania, Ohio, New York, and West Virginia) are more than 100 years old and entirely lack cement zonal isolation methods. Study author Jonathan Buonocore said, "Partly because no federal safety regulations apply to natural gas storage wells or their operations (now pending), very little aggregate information was available. . . . After we identified this data gap, we realized we needed to build our own database to begin to assess this previously

[869] U.S. Government Accountability Office. (2017, November 22). *Natural gas storage: Department of Transportation could take additional steps to improve safety enforcement planning*. GAO-18-89. Retrieved from https://www.gao.gov/assets/690/688553.pdf.

[870] Nemec, R. (2017, June 21). PHMSA pauses stricter natural gas storage rules for clarification. *Natural Gas Intel*. Retrieved from http://www.naturalgasintel.com/articles/110856-phmsa-pauses-stricter-natural-gas-storage-rules-for-clarification

inapparent hazard." With the 50 percent increase in domestic natural gas production over the last ten years, natural gas storage is at an all time high and in demand.[871, 872]

- October 21, 2016 – The California Air Resources Board determined that the Aliso Canyon gas storage facility released 100,000 tons of methane, becoming the largest ever natural gas leak in U.S. history.[873]

- October 18, 2016 – A federal task force issued a report with 44 recommendations intended to prevent another Aliso Canyon-style disaster. Chief among them is a phase-out of "single-point of failure" designs.[874]

- July 13, 2016 – As reported by the *Los Angeles Daily News,* Los Angeles County health officials were prepared to go to court to ensure that the Southern California Gas Company complies with an order to pay for professional comprehensive cleaning in the homes of residents who were relocated due to the Aliso Canyon gas leak. The company had filed legal papers asking that the order "to remove dust and oily mist from up to 35,000 homes be nullified," after their report of having cleaned 1,700 homes to date. The Los Angeles County Health Department said the company had done a poor job on these and did not follow protocol to remove the metal particles, including barium, manganese, vanadium, aluminum, and iron previously identified in household surface dust.[875]

- July 9, 2016 – California's South Coast Air Quality Management District and Southern California Gas Company were still at an impasse seven months after the company was given an abatement order that included a community health study on the potential impacts of exposures from the massive Aliso Canyon leak. The company was ordered to commit to paying "reasonable costs" for the study.[876]

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[871] Michanowicz, D. R., Buonocore, J. J., Rowland, S. T., Konschnik, K. E., Goho, S. A., & Bernstein, A.S. (2017). A national assessment of underground gas storage identifying wells with designs likely vulnerable to a single-point-of-failure. *Environmental Research Letters*, *12*(6). doi: 10.1088/1748-9326/aa7030

[872] Institute of Physics. (2017, May 24). Study uncovers widespread leak risk for US underground natural gas storage wells. *Phys.Org.* Retrieved from https://phys.org/news/2017-05-uncovers-widespread-leak-underground-natural.html

[873] California Air Resources Board (2016, October 21). Determination of total methane emissions from Aliso Canyon natural gas leak incident. Retrieved from https://www.arb.ca.gov/research/aliso_canyon/aliso_canyon_methane_emissions-arb_final.pdf

[874] U.S. Department of Energy and U.S. Department of Transportation's Pipeline and Hazardous Materials Safety Administration. (2016, October 18). Ensuring safe and reliable underground natural gas storage: Final report of the interagency task force on natural gas storage safety. Retrieved from https://energy.gov/sites/prod/files/2016/10/f33/Ensuring%20Safe%20and%20Reliable%20Underground%20Natural%20Gas%20Storage%20-%20Final%20Report.pdf

[875] Abram, S. (2016, July 13). SoCalGas slammed for poor cleanup of Porter Ranch homes. *Los Angeles Daily News.* Retrieved from http://www.dailynews.com/health/20160713/socalgas-slammed-for-poor-cleanup-of-porter-ranch-homes

[876] Bartholomew, D. (2016, July 9). Gas Company, pollution agency at odds over cost of Porter Ranch health study. *Los Angeles Daily News.* Retrieved from http://www.dailynews.com/government-and-politics/20160709/gas-company-pollution-agency-at-odds-over-cost-of-porter-ranch-health-study

- June 22, 2016 – The first federal legislation of gas storage facilities was signed into law. The Protecting our Infrastructure of Pipelines and Enhancing Safety Act of 2016 includes a provision in response to the Aliso Canyon gas leak requiring the Pipeline and Hazardous Materials Safety Administration to develop regulations for the construction and operation of underground natural gas storage facilities.[877] (See entry below, of February 8, 2016, for analysis of the likely shortcomings of these first federal regulations and their inability to prevent a leak such as that at Aliso Canyon.)

- June 20, 2016 – As reported in *Geophysical Research Letters*, an airborne instrument onboard a NASA satellite was able to detect and quantify the size and shape of the methane plume from the Aliso Canyon gas leak as the event occurred.[878] This is the first time a natural gas leak has been visible from space, according to the authors of the study.[879]

- May 4, 2016 – Southern California Gas Company said that costs related to the Aliso Canyon natural gas storage facility leak reached an estimated $665 million. The utility company let the Securities and Exchange Commission know they carry policies with a combined limit available "in excess of $1 billion," but according to the *Los Angeles Times*, legal experts and lawyers said that $1 billion in insurance might not be enough for what they ultimately need.[880]

- April 12, 2016 – California energy agencies issued a report indicating the threat of widespread summer power outages if no gas can be withdrawn from Aliso Canyon. The report was met with criticism. "Consumer groups and utility critics contend that the blackout warnings are an irresponsible scare tactic to ensure that Southern California Gas Company is allowed to keep storing gas at the facility and that ratepayers will pay for upgrades to store even more fuel there."[881]

- April 6, 2016 – The *Los Angeles Times* reported that, though prices for homes in Porter Ranch adjacent to the Aliso Canyon gas storage leak held up, sales declined. After the leak that began October 23, 2015, sales from December 2015 to February 2016 declined 20 percent from the year before. Disclosures for homes in the area "now include a mention of the community's proximity to the gas field and the recent problems."[882]

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[877] Cama, T. (2016, June 22). Obama signs pipeline safety bill. *The Hill.* Retrieved from http://thehill.com/policy/energy-environment/284479-obama-signs-pipeline-safety-bill

[878] Thompson, D. R., Thorpe, A. K., Frankenberg, C., Green, R. O., Duren, R., Guanter, L., …Ungar, S. (2016). Space-based remote imaging spectroscopy of the Aliso Canyon CH_4 superemitter. *Geophysical Research Letters* 43(12). doi: 10.1002/2016GL069079

[879] Mooney, C. (2016 June 15). This gas leak was so massive that NASA saw it from space. *The Washington Post.* Retrieved from https://www.washingtonpost.com/news/energy-environment/wp/2016/06/15/this-gas-leak-was-so-massive-that-nasa-saw-it-from-space/?utm_term=.1e66d8da1423

[880] Penn, I. (2016, May 4). Costs related to Aliso Canyon leak reach an estimated $665 million. *Los Angeles Times.* Retrieved from http://www.latimes.com/business/la-fi-aliso-canyon-costs-20160504-snap-story.html

[881] Penn, I. (2016, April 12). 'This is a threat. This is not a report.' Critics call blackout warnings a scare tactic to keep Aliso Canyon open. *Los Angeles Times.* Retrieved from http://www.latimes.com/business/la-fi-gas-field-20160412-story.html

[882] Khouri, A. (2016, April 6). Gas leak disrupts Porter Ranch housing market. *Los Angeles Times.* Retrieved from http://www.latimes.com/business/realestate/la-fi-porter-ranch-sales-20160406-story.html

- March 18, 2016 – The California State Oil and Gas Division of the Department of Conservation issued penalties totaling $75,000 for three separate violations after finding incidents of intentional venting of gas at the Aliso Canyon gas field and malicious concealment of those acts. Both are violations of the state gas regulations.[883] Following the Aliso Canyon gas storage leak, the California State Public Utilities Commission ordered a statewide survey of California's 12 natural gas storage fields and found 229 faulty valves, flanges and leaky wellheads and a 230th leak at an abandoned well; eight were deemed hazardous.[884]

- March 14, 2016 – Methane and ethane emissions were measured to determine spatial patterns and source attribution of urban methane in the Los Angeles Basin. The surveys demonstrated the prevalence of fugitive methane emissions across the Los Angeles urban landscape and that fossil fuel sources accounted for 58–65 percent of methane emissions.[885]

- February 25, 2016 – Measurements of methane and other chemicals were taken by aerial equipment following the October gas release from a faulty well in the Aliso Canyon storage field. The data demonstrated that the blowout of this single well created the largest known anthropogenic point source of methane in the United States. The leak lasted 112 days and released a total of 97,100 tons of methane and 7,300 tons of ethane into the atmosphere. This was equal to 24 percent of the methane and 56 percent of the ethane emitted each year from all other sources in the Los Angeles Basin combined.[886] Aliso Canyon was already a major pollution source before the massive leak.[887] As determined by the study and reported by major news outlets, the recent methane link is officially the worst in U.S. history.[888, 889]

- February 18, 2016 – Stanford and UCLA scientists reported to *InsideClimate News* that the lack of measurement data for the entire 100+ days of community exposures to the

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[883] California Department of Conservation. (2016, March 18). State oil & gas division issues $75,000 fine to operator for illegally venting natural gas. NR#2016-06. Retrieved from http://www.conservation.ca.gov/index/Documents/2016-06%20DOC%20fines%20oil%20operator%20$75,000.pdf

[884] St. John, P. (2016, March 23). 229 leaks found in state's underground gas storage facilities, most considered minor. *Los Angeles Times.* Retrieved from http://www.latimes.com/local/lanow/la-me-ln-gas-leaks-storage-wells-20160322-story.html

[885] Hopkins, F. M., Kort, E. A., Bush, S. E., Ehleringer, J. R., Lai, C.-T., Blake, D. R., & Randerson, J. T. (2016). Spatial patterns and source attribution of urban methane in the Los Angeles Basin. *Journal of Geophysical Research: Atmospheres, 121*(5), 2490–2507. doi: 10.1002/2015JD024429

[886] Conley, S., Franco, G., Faloona, I., Blake, D. R., Peischl, J. & Ryerson, T. B. (2016). Methane emissions from the 2015 Aliso Canyon blowout in Los Angeles, CA. *Science.* Advance online publication. doi: 10.1126/science.aaf2348

[887] Lobet, I. & Reicher, M. (2016, February 14). *inewsource.org.* Retrieved from http://inewsource.org/2016/02/14/aliso-canyon-major-pollution/

[888] Akpan, N. (2016, February 25). Los Angeles methane leak was officially the worst in U.S. history, study says. *PBS Newshour.* Retrieved from http://www.pbs.org/newshour/rundown/los-angeles-methane-leak-is-officially-the-worst-in-u-s-history/

[889] Khan, A. (2016, February 25). Porter Ranch leak declared largest methane leak in U.S. history. *Los Angeles Times.* Retrieved from http://www.latimes.com/science/sciencenow/la-sci-sn-porter-ranch-methane-20160225-story.html

Aliso Canyon methane leak, combined with gaps in the science about many of the chemicals, hinders the ability to understand the health impacts of the leak. "'The first week is when we would expect the highest gas concentrations to reach the neighborhood because the pressures in the storage field were the highest,' said Robert Jackson, an earth system science professor at Stanford University who measured methane concentrations in nearby communities during the leak. 'And yet we don't have any information or data for that first week at least.'" Jackson noted that even after monitoring was initiated, it was intermittent rather than continuous.[890]

- February 18, 2016 – Independent regional experts from USC and UCLA interviewed by Southern California Public Radio expressed skepticism that an industry-funded study ordered by the South Coast Air Quality Management District following the Aliso Canyon methane leak would be rigorously designed to answer specific questions about sub-chronic, cumulative exposures, including hydrogen sulfide, which was measured in the nearby Porter Ranch community at levels far greater than the average across American cities.[891]

- February 13, 2016 – The Los Angeles County Department of Health prepared a *Supplemental Report* for its Expanded Air Monitoring Plan concerning the Southern California Gas Company's Aliso Canyon storage facility long-term gas leak. The report addressed "chemicals of health concern" including toluene, ethylbenzene, xylene, hydrocarbons, VOCs, metals, and radon and concluded, "all results suggest that chemical exposures experienced by residents as a result of the gas leak are below the levels of concern that have been established by various regulatory agencies."[892] Remaining challenges named by the report itself included possible gaps in data collection, other chemicals present for which no sampling occurred, and further study of the symptoms reported by the public. Many independent scientists did not concur with the Department of Health's ongoing statements that chemical exposures were below levels of concern. Issues raised included monitoring not initiated until a week after the leak began, lack of continuous monitoring, and reliance on "grab samples." Speaking to *InsideClimate News,* John Bosch, a retired air-monitoring expert with more than 30 years' experience at the EPA said, "Grab samples may be OK as a first-tier guestimate of what the problem is, but you really have to have continuous monitoring."[893]

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890 McKenna, P. (2016, February 18). What will be the health impact of 100+ days of exposure to California's methane leak? *InsideClimate News*. Retrieved from http://insideclimatenews.org/news/17022016/health-impacts-aliso-canyon-porter-ranch-methane-leak-california-socal-gas

891 O'Neill, S. (2016, February 18). Did the Porter Ranch gas leak cause long-term health damage? *89.33 KPCC*. Retrieved from http://www.scpr.org/news/2016/02/18/57666/did-the-porter-ranch-gas-leak-cause-long-term-heal/

892 Los Angeles County Department of Health. (2016, February 13). ALISO CANYON GAS LEAK Results of Air Monitoring and Assessments of Health, SUPPLEMENTAL REPORT: Updated Results and Expanded Chemical Testing. Retrieved from http://www.publichealth.lacounty.gov/media/docs/SUPPLEMENTAL%20-Aliso%20Canyon%20Gas%20Leak-%20Results%20of%20Air%20Monitoring%20and%20Assessments%20of%20Health%20-%202-13-16.pdf

893 McKenna, P. (2016, February 18). What will be the health impact of 100+ days of exposure to California's methane leak? *InsideClimate News*. Retrieved from https://insideclimatenews.org/news/17022016/health-impacts-aliso-canyon-porter-ranch-methane-leak-california-socal-gas

- February 8, 2016 – The Pipeline and Hazardous Materials Safety Administration (PHMSA) announced that it might issue its first federal safety regulations for gas storage sites such as Aliso Canyon, while also suggesting site operators voluntarily follow guidelines that the proposed rules (which would likely take years to issue) will likely mirror. According to a report in *InsideClimate News*, these guidelines would not require systems to stop the flow of gas in an emergency or mandate redundancies to prevent methane from leaking into the environment." If PHMSA proceeds to adopt industry guidelines, the resulting rules "may not address two key issues that turned Aliso Canyon into a disaster: emergency shutoff valves and a safer configuration of pipes." Further, even with new regulations, storage units would most likely remain under state jurisdiction, "though state authorities may adopt any new federal rules."[894] A subsequent story reported on members of Congress pressing PHMSA to create the first federal standards for the 418 underground gas storage facilities for which it has authority to set regulations. In the hearing before a subcommittee of the House Committee on Transportation and Infrastructure, California representatives "spoke about their efforts to speed up PHMSA's rulemaking for underground gas storage."[895]

- February 5, 2016 – As part of the Expanded Air Monitoring Plan, Los Angeles County Department of Health provided results for the primary chemicals of concern to assess health effects in residents, pets, and other animals in the community during the Southern California Gas Aliso Canyon storage facility leak. Those chemicals included methane, odorants, and benzene. The maximum level of methane detected was 4,340 ppm and the maximum level of benzene was 30.6 ppb. Early on, average weekly benzene levels that were close to the 1 ppb chronic exposure limit/ health protective level. "Methane levels have remained above normal, but have decreased substantially over time," the report summarized. It also stated that odorants "… remained below instrument detection limits throughout the entire period, including immediately after the leak, even at locations near the leaking well," and that "[b]enzene and other chemicals were originally detectable at levels above normal from within community sampling sites, but peak levels remained below acute exposure thresholds."[896] While the Los Angeles County Department of Health concluded that "health effects resulting from the on-going leak should be limited to short-term effects resulting from exposure to the odorants," independent scientists, noting data gaps, have challenged these conclusions.

- January 25, 2016 – Some health experts and residents of Porter Ranch, California, adjacent to the Aliso Canyon gas field leak, expressed concern about long-term exposure to the odorous component of the gas, mercaptans, to which regulators attributed several symptoms of residents. Mercaptans are sulfurous chemicals that are added to natural gas to aid in the detection of leaks. Though California regulators have said the health

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[894] McKenna, P. (2016, February 8). New federal gas storage regulations likely to mimic industry's guidelines. *InsideClimate News*. Retrieved from https://insideclimatenews.org/news/08022016/federal-gas-storage-regulations-likely-mimic-industry-guidelines-aliso-canyon-phmsa-api

[895] Song, L. (2016, February 26). *InsideClimate News*. U.S. pipeline agency pressed to regulate underground gas storage. Retrieved from https://insideclimatenews.org/news/26022016/phmsa-pipeline-regulator-pressed-regulate-underground-natural-gas-storage-aliso-canyon-methane

[896] Los Angeles County Department of Health. (2016, February 5). Aliso Canyon gas leak: Results of air monitoring and assessments of health. Retrieved from http://www.publichealth.lacounty.gov/media/docs/AlisoAir.pdf

problems, such as headaches, vomiting, and nosebleeds are temporary and will not lead to long-term damage, medical researchers described data gaps to *InsideClimate News.* There is "virtually no research on prolonged exposure to mercaptans." Further, some researchers suggest the health problems may have been caused by different chemicals in the gas, and that "regulators have downplayed the significance of other contaminants that are also present in the leak."[897]

- January 19, 2016 – Peter Richman, MD, president of the Los Angeles County Medical Association told the *Los Angeles Daily News* that, at nearly three months after the Aliso Canyon methane leak began, physicians had yet to receive a formal statement from the Los Angeles County Department of Public Health about airborne chemical pollutants related to the gas leak or guidelines on how to answer questions from patients about long-term health effects. Richman expressed special concern about prolonged exposure to methane and trace chemicals known to be carcinogenic. Another area physician reported that, as of the interview date, his urgent care practice had seen a hundred patients whose symptoms were consistent with exposure to leak-related pollutants.[898]

- January 14, 2016 – Boston University researcher Nathan Phillips and Bob Ackley of Gas Safety USA drove a high precision GIS-enabled gas analyzer through roads throughout California's San Fernando Valley adjacent to the Aliso Canyon gas leak in early January 2016. Early results showed methane levels elevated 2-67 times the background level.[899]

- January 13, 2016 – Investigations into the possible cause of the gas leak in Aliso Canyon included the consideration that nearby fracking may have contributed to casing failure. In an email to the *Los Angeles Daily News*, California Department of Conservation Chief Deputy Jason Marshall said that their investigation will examine well records, including those pertaining to "well stimulation operations."[900] According to a 2015 report prepared for the California Council on Science and Technology, hydraulic fracturing is used about twice yearly to enhance storage "mostly in one facility serving southern California (Aliso Canyon)."[901]

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[897] Song. L. (2016, January 25). Mercaptans in methane leak make Porter Ranch residents sick, and fearful. *InsideClimate News.* Retrieved from https://insideclimatenews.org/news/22012016/porter-ranch-residents-health-effects-methane-leak-aliso-canyon-california

[898] Abram, S. (2016, January 19,). Doctors treating Porter Ranch residents want more gas-leak guidance. *Los Angeles Daily News*. Retrieved from http://www.dailynews.com/health/20160119/doctors-treating-porter-ranch-residents-want-more-gas-leak-guidance

[899] Bartholomew, D. (2016, January 14). 'Plume chaser' researchers fan out across San Fernando Valley to map reach of Porter Ranch gas leak. *Los Angeles Daily News.* Retrieved from http://www.dailynews.com/environment-and-nature/20160114/plume-chaser-researchers-fan-out-across-san-fernando-valley-to-map-reach-of-porter-ranch-gas-leak

[900] Wilcox, G. J. (2016, January 13). Regulators probing whether fracking was connected to Aliso Canyon gas well leak. *Los Angeles Daily News.* Retrieved from http://www.dailynews.com/environment-and-nature/20160113/regulators-probing-whether-fracking-was-connected-to-aliso-canyon-gas-well-leak

[901] Long, J. C. S., Feinstein, L. C., Birkholzer, J., Jordan, P., Houseworth, J., Dobson, P. F., . . . Gautier, D. L. (2015). *An independent scientific assessment of well stimulation in California, Volume I: Well stimulation technologies and their past, present, and potential future use in California.* California Council on Science and Technology, Sacramento, CA. Retrieved from https://ccst.us/publications/2015/2015SB4-v1.pdf

- January 13, 2016 – "Aliso Canyon is a wake-up call," according to a *Rocky Mountain PBS News* investigative report on the state of U.S. natural gas infrastructure. Natural gas is no longer a cleaner fuel than coal when methane leakage rates exceeds 2-4 percent, but the vast size of the nation's interconnected natural gas storage and pipeline systems makes difficult the task of tallying all the micro-leaks spread across the entire network and answering fundamental questions about exactly how much methane is being lost. The PBS report also expressed concern about the age of many of the system's component parts. According to the piece, nearly half (46 percent) of the nation's transmission pipelines, designed to carry high-pressure gas over long distances, were built in the 50s and 60s and are now more than a half century old.[902]

- December 30, 2015 – According to the *Los Angeles Daily News*, which unearthed November 2014 state regulatory filing documents, the Southern California Gas Company knew about the corrosion and potential for leakage at Aliso Canyon prior to the massive blow-out. "In written testimony to the California Public Utilities Commission, [SoCalGas Director of Storage Operations Phillip] Baker described a reactive maintenance process that hinted at major leakage problems underground."[903]

- November 20, 2015 – California state agencies collaborated with Aviation Scientific to measure methane emission rates at two early November dates, finding rates of 44,000±5,000 kilograms of methane per hour and 50,000±16,000 kilograms of methane per hour. The results indicated that the Aliso Canyon gas leak would have contributed about a quarter of California's methane emissions for the time period studied.[904]

- November 20, 2015 – According to the *Los Angeles Times*, one month into the Aliso Canyon ongoing gas leak, Southern California Gas warned that it "might need several months" to plug the leak. An order from California's Division of Oil, Gas and Geothermal Resources, "stated that an 'uncontrolled flow of fluids' and gas was escaping and the operator had failed to fully inform state officials about the well's status. Steve Bohlen, the state oil and gas supervisor, also directed the company to submit a schedule for remediation work or for drilling a relief well."[905]

- October 19, 2015 – *Houston Public Media* reported on the 125 caverns carved out of salt storing natural gas liquids (NGLs), thousands of feet under the city of Mont Belvieu, Texas, east of Houston. "There have been fiery accidents here. But nothing like what

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[902] Wirfs-Brock, J. (2016, January 13). Vast California methane leak is dire but not unique in aging infrastructure. *Rocky Mountain PBS News.* Retrieved from http://inewsnetwork.org/2016/01/13/vast-california-methane-leak-is-dire-but-not-unique-in-aging-infrastructure/

[903] Reicher, M. (2015, December 30). SoCalGas knew of corrosion at Porter Ranch gas facility, doc shows. *Los Angeles Daily News*. Retrieved from http://www.dailynews.com/general-news/20151230/socalgas-knew-of-corrosion-at-porter-ranch-gas-facility-doc-shows

[904] California Air Resources Board. (2015, November 20). Report on greenhouse gas emissions from Aliso Canyon leak. *Los Angeles Times.* Retrieved from http://documents.latimes.com/report-greenhouse-gas-emissions-aliso-canyon-leak/

[905] Barboza, T. (2015, November 20). Natural gas leak that's sickening Valley residents could take months to fix. *Los Angeles Times.* Retrieved from http://www.latimes.com/local/california/la-me-1121-gas-leak-20151121-story.html

happened 23 years ago at a different [NGL] storage site 100 miles to the west. 'A bomb-like blast literally blew residents in this small community out of their beds this morning, said a reporter for Dallas's Channel 8 as he did a live report just outside the city of Brenham." That blast, which killed three and injured 21, was reportedly caused by the lack of an emergency shut-off valve. There are no federal standards in place for such requirements. Twenty-three years later, a month prior to the *Houston Public Media* report, "at a hearing held by the U.S. Senate Committee on Commerce, Science, & Transportation, Donald Santa, head of the Interstate Natural Gas Association of America, told the senators that it was only in recent weeks that the industry approved standards for storing natural gas." Texas did enact legislation a year after the deadly blast "and now requires emergency shutoff valves and inspections for leaks every five years."[906]

- October 5, 2011 – The federal district court in Topeka struck down Kansas gas-safety laws in 2010, and 11 underground storage sites with a capacity of more than 270 billion cubic feet of gas have gone uninspected, leaving thousands of Kansans to live on and around uninspected gas-storage fields.[907]

- 2008 – When considering the possibility of storing natural gas in a variety of underground gas storage facilities, the UK government commissioned the British Geological Survey to identify the main types of facilities currently in operation worldwide along with any documented or reported failures and incidents which have led to release of stored product. The researchers found that California had the most incidents, but concluded that many of these problems and geological factors would not necessarily be applicable to the UK. The incidents most relevant to gas storage in the UK resulted from a failure of either the man-made infrastructure (well casings, cement, pipes, valves, flanges, compressors etc.), or human error, which has included overfilling of caverns and inadvertent intrusion. Extreme natural events, including earthquakes, also played a role. The researchers looked closely at incidents in salt caverns that had been repurposed to store gas. They reported that "early salt cavern storage in the US was done in brine wells that had been solution mined [in which salt deposits are melted away with hot water or steam] without consideration for subsequent storage in the depleted caverns. This practice sometimes resulted in later problems for storage operations in retrofitted brine caverns." The authors conclude that the rate for a geological failure of the storage cavity in an underground gas storage facility is of the order of 10^{-5} failures per well year.[908]

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[906] Fehling, D. (2015, October 19). On edge of Houston, underground caverns store huge quantities of natural gas liquids. *Houston Public Media*. Retrieved from http://www.houstonpublicmedia.org/articles/news/2015/10/19/124674/on-edge-of-houston-underground-caverns-store-huge-quantities-of-natural-gas-liquids/

[907] Lefler, D. (2011, October 5). Lawsuit leaves large gas storage fields in Kansas unregulated. *Wichita Eagle.* Retrieved from http://www.kansas.com/news/article1071558.html

[908] Keeley, D. (Health and Safety Laboratory). 2008. *Failure rates for underground gas storage: Significance for land use planning assessments.* Health and Safety Laboratory for the Health and Safety Executive, Derbyshire, UK. Retrieved from http://www.hse.gov.uk/research/rrpdf/rr671.pdf

Liquefied natural gas (LNG) facilities

- November 20, 2017 – Using a hybrid lifecycle and energy strategy analysis, a team of energy researchers investigated the potential climate impacts of U.S. LNG exports to Asia. They found that gas emissions were widely variable, dependent on the specific destination and the ultimate purpose for which the gas is used. Despite this range, under a scenario in which U.S. LNG exports continue to rise, "emissions are not likely to decrease and may increase significantly" because of additional energy demand, higher U.S. emissions, and increased methane leakage. The study also predicted that increased LNG exports could actually prolong the lifespans of coal-fired plants within the United States. All together, these factors, "have the very real potential to undermine any prospective climate benefit in the long run." Going forward, policymakers must consider "the complete climate ramifications of LNG exports."[909] *E&E News,* reporting on the study, quoted one of the authors as saying, "The implications of our paper are that the greenhouse gas impacts from exporting U.S. natural gas…here at home and abroad, can be very, very bad."[910]

- July 25, 2017 – Citing volatile market conditions, Malaysia's energy giant Petronas cancelled plans for a massive LNG export terminal at the mouth of the Skeena River on British Columbia's remote northwest coast in Canada. As reported extensively by *The Tyee,* the project was the target of intense protest by First Nations people and the subject of many lawsuits, as it threatened public health and would industrialize pristine salmon habitat. "At one time as many as twenty LNG projects were proposed for coastal communities, but not one has been built. The majority of largely Asian-backed proponents have now cancelled or deferred their projects. A 50 percent drop in global oil prices combined with a 70 percent drop in global LNG prices forced Petronas to…scuttle a number of projects over the last two years."[911]

- July 10, 2017 – Using a lifecycle assessment and optimization analysis to forecast the environmental impacts of LNG, researchers modeled three usage scenarios: hydrogen production; electricity generation; and vehicle fuel. The model assumed LNG transport by pipeline only, and not by tanker. The highest environmental impact in each case was global warming potential (GWP), and the highest GWP occurred when LNG was used as vehicle fuel.[912]

- March 30, 2017 – Transportation researchers identified and assessed potential risks to public safety from LNG transport on inland waterways and as a fuel for vessels and

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[909] Gilbert, A. Q., & Sovacool, B. K. (2017). US liquefied natural gas (LNG) exports: Boom or bust for the global climate? *Energy, 141*, 1671-1680. doi: 0.1016/j.energy.2017.11.098

[910] Gilmer, E. M., & Mandel, J. (2017, December 15). Increased LNG exports would spell trouble for climate – study. *E&E News.* Retrieved from https://www.eenews.net/stories/1060069129

[911] Nikiforuk, A. (2017, July 25). 'Basic economics' kill $11-billion LNG project on BC's coast. *The Tyee.* Retrieved from https://thetyee.ca/News/2017/07/25/LNG-Project-BC-Coast-Killed/?utm_source=facebook&utm_medium=social&utm_content=072517-4&utm_campaign=editorial-0717

[912] Zhang, Y., Jiang, H., Li, J., Shao, S., Hou, H., Qi, Y., & Zhang, S. (2017). Life cycle assessment and optimization analysis of different LNG usage scenarios. *International Journal of Life Cycle Assessment.* Advance online publication. doi: 10.1007/s11367-017-1347-2

ferries. The hazards included the possibility of collision with other ships or with stationary objects such as bridges, as well as the threats of vapor release, flash and jet fires, boiling liquid expanding vapor explosion, and rapid phase transition. Firefighting strategies for different scenarios were proposed.[913]

- March 9, 2017 – Liquefaction, LNG transport, and LNG evaporation determined more than 50 percent of LNG's global warming potential (GWP) in a "cradle to gate" life cycle analysis of LNG imported to the UK from Qatar. The analysis confirmed the dangerous effect of fugitive methane emissions on the total GWP of the supply chain. Other important parameters affecting GWP included the shipping distance and the tank volume.[914]

- December 22, 2016 – Methane emissions from the heavy-duty transportation sector have climate change implications, according to a "pump-to-wheels" evaluation of natural gas powered vehicles and the compressed natural gas and LNG stations that fuel them. While fueling stations themselves leak methane, tailpipe and crankcase emissions were the highest sources.[915]

- May 2, 2016 –The potential economic and greenhouse gas (GHG) impacts of importing LNG to Hawaii for electricity generation was modeled. Methane is a potent GHG, and although the use of LNG would decrease the local GHG output of Hawaii's electrical sector, lifecycle (global) GHG emissions would likely increase. This study did not examine other potential environmental impacts of LNG. Currently, the majority of Hawaii's electricity is provided by oil-fired generation.[916]

- November 12, 2015 – New York Governor Andrew Cuomo rejected a heavily contested proposal to construct an LNG terminal 19 miles off the coast of Long Island. From his letter to the Maritime Administration: "The security and economic risks far outweigh any potential benefits….The potential for disaster with this project during extreme weather or amid other security risks is simply unacceptable." The governor also noted the risks posed to scallop and squid fisheries as well as the project's conflict with a proposed large-scale, offshore wind farm.[917]

- September 30, 2015 – Measurements of the gaseous and particulate emissions of a cruise ferry on the Baltic Sea using a dual-fuel engine showed that LNG is not a clean fuel for

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[913] Galieriková, A., Kalina, T., & Sosedová, J. (2017). Threats and risks during transportation of LNG on European inland waterways. *Transport Problems,12*(1), 73-81. doi: 10.20858/tp.2017.12.1.7
[914] Tagliaferri, C., Clift, R., Lettieri, P., & Chapman, C. (2017). Liquefied natural gas for the UK: A life cycle assessment. *International Journal of Life Cycle Assessment, 22*, 1944–1956. doi: 10.1007/s11367-017-1285-z
[915] Clark, N. N., McKain, D. L., Johnson, D. R., Wayne, W. S., Li, H., Akkerman, V., … Ugarte, O. J. (2017). Pump-to-wheels methane emissions from the heavy-duty transportation sector. *Environmental Science & Technology, 51*(2), 968-976. doi: 10.1021/acs.est.5b06059
[916] Coffman, M., Bernstein, P., Wee, S., & Schafer, C. (2017). Economic and GHG impacts of natural gas for Hawaii. *Environmental Economics and Policy Studies, 19*, 519–536. doi: 10.1007/s10018-016-0157-2
[917] Santora, M. (2015, November 12). Cuomo rejects natural gas port proposed off Long Island. *The New York Times.* Retrieved from https://www.nytimes.com/2015/11/13/nyregion/cuomo-rejects-natural-gas-port-proposed-off-long-island.html?_r=0

ships. Methane made up about 85 percent of the vessel's hydrocarbon emissions. Particulate emissions showed a huge amount of volatile and nonvolatile particles, both of which are hazardous to human health.[918]

- September 26, 2014 – The GAO issued a report of the federal process for reviewing applications to export LNG. As part of the process, the Department of Energy (DOE) and FERC consider public comment. Numerous environmental concerns include the risk that exports will increase hydro-fracking for natural gas, along with its associated environmental effects and greenhouse gas emissions. Under the National Environmental Policy Act, the DOE must consider the environmental effects of its decisions.[919]

- April 23, 2014 –The dynamics and hazards from a LNG spill are not well understood and require further research, according to a comprehensive review of research into the LNG production chain from Australia that examined vapor production, vapor dispersion, and mechanisms of combustion. Noting the "intrinsic process safety issues" of LNG as well as potential attraction as a terrorist target, authors described various threats to human safety, including pool fires, jet fires, and vapor cloud explosions.[920]

- December 14, 2009 – Certain LNG hazards are not "understood well enough to support a terminal siting approval," according to a Congressional Research Service (CRS) report that summarizes LNG hazards in the context of federal rules related to where LNG terminals are located. Potential risks include pool fires and flammable vapor clouds, as well as the possibility of terrorist attacks. The analysis points out the need for additional LNG safety research.[921]

- July 7, 2009 – Because LNG projects are among the most expensive energy projects, the reserves of gas to justify the investment need to be large enough to guarantee about 30 years of production, according to a report by the Joint Research Centre of the European Union.[922]

- May 13, 2008 – LNG infrastructure is "inherently hazardous and it is potentially attractive to terrorists," according to a CRS study that was prepared at a time when the United States was a net importer of LNG. Security of tankers, import terminals, and inland storage plants were identified as issues of concern. Serious risks include pool fires with intense heat, which can occur when LNG spills near an ignition source; flammable vapor clouds that can drift until reaching an ignition source; and a rapid phase transition

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918 Anderson, M., Salo, K., & Fridell, E. (2015). Particle- and gaseous emissions from an LNG powered ship. *Environmental Science & Technology, 49,* 12568−12575. doi: 10.1021/acs.est.5b02678
919 U.S. Government Accountability Office. (2014, September). *Federal approval process for liquefied natural gas exports.* GAO-14-762. Retrieved from https://www.gao.gov/assets/670/666177.pdf
920 Ikealumba, W. C., & Wu, H. Some recent advances in liquefied natural gas (LNG) production, spill, dispersion, and safety. *Energy & Fuels, 28(6),* 3556–3586. doi: 10.1021/ef500626u
921 [Name redacted]. (2009, December). *Liquefied natural gas (LNG) import terminals: Siting, safety, and regulation.* Congressional Research Service. RL32205. Retrieved from https://www.everycrsreport.com/files/20091214_RL32205_e95cb50c88dbd56a2c8f706b2d521ef7ae81ee00.pdf
922 Kavalov, B., Petric, H., & Georgakaki, A. (2009). *Liquefied natural gas for Europe—some important issues for consideration.* European Commission Joint Research Centre, Reference Report. doi: 10.2790/1045.

that can generate a flameless explosion. As per this report, there have been 13 serious accidents at onshore LNG terminals since 1944.[923]

- February 22, 2007 – The GAO examined the results of studies on the consequences of an LNG spill and discussed expert opinion about the consequences of a terrorist attack on an LNG tanker. The studies indicate that 30 seconds of exposure to the heat of an LNG fire could cause burns up to a distance of about one mile. The experts concluded that this would be the most likely public safety hazard, with the risk of explosion less likely. Recommendations were made for further studies, including evaluating the possibility of "cascading failure," where multiple LNG tanks on a ship might fail in sequence.[924]

- September 9, 2003 – As part of a larger investigation of potential terrorist targets in wake of the 9/11 attacks, the CRS provided a background report to the U.S. Congress on the security of LNG terminals in the United States. At the time, the United States was a net importer of natural gas, and LNG was shipped from overseas to U.S. ports. CRS identified LNG tanker ships and storage infrastructure as "vulnerable to terrorism," noting that tankers could be turned as weapons against coastal cities and that inland LNG facilities are typically located near large population centers. The CRS further noted that the public cost of security for LNG shipments, via Coast Guard escorts of tankers through coastal shipping channels, was considerable ($40,000-$80,000 per tanker).[925]

- August 1, 1995 – The U.S. Department of Transportation identified three important hazardous properties of LNG: flammability hazards (fire or explosion from ignition of leaks); toxicity hazards (asphyxiation from exposure to non-odorized fuel gas); cryogenic hazards (personal injury plus structural failure of equipment from prolonged exposure to extremely cold temperatures.)[926]

Inaccurate jobs claims, increased crime rates, threats to property values and mortgages, and local government burden

Experiences in various states and accompanying studies have shown that the oil and gas industry's promises of job creation from drilling for natural gas have been greatly exaggerated. Many of the jobs are short-lived, have gone to out-of-area workers, and, increasingly, are lost to automation. With the arrival of drilling and fracking operations, communities have experienced steep increases in rates of crime, including assault, rape, larceny, and auto theft.

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[923] Parfomak, P. W. (2008, May). *Liquefied natural gas (LNG) infrastructure security: Issues for Congress.* Congressional Research Service. RL32073. Retrieved from https://www.hsdl.org/?view&did=486464

[924] U.S. Government Accountability Office. (2007, February). *Public safety consequences of a terrorist attack on a tanker carrying liquefied natural gas need clarification.* GAO-07-316. Retrieved from https://www.gao.gov/new.items/d07316.pdf

[925] Congressional Research Service. (2003, September 9). *Liquefied natural gas (LNG) infrastructure security: Background and issues for Congress*. Retrieved from http://www.energy.ca.gov/lng/documents/CRS_RPT_LNG_INFRA_SECURITY.PDF

[926] U.S. Dept. of Transportation, Federal Transit Administration. (1995, August 1). *Summary of assessment of the safety, health, environmental and system risks of alternative fuel*. Retrieved from https://rosap.ntl.bts.gov/view/dot/8403

Crime rates have increased even with additional allocation of funds for public safety. Financial and other strains on municipal services include those on law enforcement, road maintenance, emergency services, and public school district administration. In Texas alone, road damage and other transportation impacts costs an estimated $1.5-$2 billion a year. In shale boom areas across the United States, school districts report heightened stress, regardless of whether student funding increased or decreased. Economists are increasingly quantifying community quality of life impacts and the unequal distribution of costs and benefits associated with drilling and fracking. Drilling and fracking pose an inherent conflict with mortgages and property insurance due to the hazardous materials used and the associated risks. The departure of drilling and fracking operations from communities eases some of these challenges but can also lead to additional economic harm such as by a sharp uptick in foreclosures, late car and mortgage payments, empty housing units, and failed or diminished local businesses.

- September 26, 2017 – The partial abandonment of the Eagle Ford Shale dramatically hurt small business owners, according to a report by *Bloomberg.* "As the shale drillers moved on to richer fields, the South Texas landscape became pockmarked with abandoned structures. This nimbleness—the ability to just pack up and leave at a moment's notice—may give U.S. oil companies a competitive advantage against their more rigid state-run OPEC rivals, but there is a human cost to it all." Concerning one tool and supply company in the region, the investigation found: "During the height of the Eagle Ford boom, R. Katz was supplying as many as 52 rigs and employing as many as 18 people in its office outside Cuero's main strip. Today, it's got 11 rig clients and three employees."[927]

- August 10, 2017 – Researchers from the independent, nonpartisan economic research group Resources for the Future studied the impacts of unconventional oil and gas booms on public school districts in the oil- and gas-producing states Pennsylvania, Ohio, West Virginia, North Dakota, Montana, and Colorado between 2000 and 2013. Using quantitative data analysis as well as extensive interviewing with parents and students in the districts, the study addressed the effects of recent oil and gas booms on student enrollment, teachers, public education finances, and student achievement metrics. Though divergent trends were found between school districts in the eastern versus western U.S., "nearly all boom districts reported heightened stress from financial volatility." Though some districts had a statistically positive increase in per student funding while others had a decline, "the study found that greater revenues do not always translate into increased educational outcomes…. One western Colorado school district had to operate on a four-day-a week schedule and cut academic programs because of increased economic volatility."[928] As reported in *U.S. News and World Report*, "the boom-and-bust cycle of the industry was found to create overwhelming stress on local

[927] Murtaugh, D. (2017, September 26). The oil ghost towns of Texas. *Bloomberg.* Retrieved from https://www.bloomberg.com/news/features/2017-09-26/the-oil-ghost-towns-of-texas
[928] Ratledge, N. & Zachary, L. (2017). *Impacts of unconventional oil and gas booms on public education: A mixed-methods analysis of six producing states.* Retrieved from http://www.rff.org/research/publications/impacts-unconventional-oil-and-gas-booms-public-education-mixed-methods

districts as students and teachers were moving in and out of a region to meet the economic demands of drilling."[929]

- June 18, 2017 – A Shale Task Force of the Academy of Medicine, Engineering and Science of Texas (TAMEST) developed the report, *Environmental and Community Impacts of Shale Development in Texas*, a "first-of-its-kind, comprehensive review of scientific research and related findings regarding impacts of shale oil and gas production in Texas." Transportation impacts included road damage costing Texas an estimated $1.5 to $2 billion a year, and rural crashes involving commercial vehicles increasing over 75 percent in some drilling regions. The number of fatal collisions in the Permian Basin doubled from 94 during 2006 to 2009, to 183 from 2010 to 2013. The report also noted that Texas is the only major oil and gas producing state without a "surface damage act" to protect landowners, who do not own the mineral rights on their land and have little control over oil and gas operations. The report, which also addressed topics such as seismicity, air, and water, noted that the various impacts of oil and gas development "can't be studied or addressed in isolation." Authors continued, "[t]hese connections are important and pervasive, but are not well-studied yet." TAMEST includes all of the state's Nobel Laureates, plus Texas-based members of the National Academies of Sciences, Engineering, and Medicine.[930]

- April 5, 2017 – Economists at Colorado State University quantified the "substantial environmental costs associated with hydraulic fracturing," as part of an analysis of the market and non-market costs and benefits of fracking in 14 U.S. states. These costs were "dominated by $27.2 billion ($12.5–$41.95 billion) health damages from air pollution." They also found costs including "$3.8 billion ($1.15–$5.89 billion) in greenhouse gas emissions, $4 billion ($3.5–$4.45 billion) in wildlife habitat fragmentation, and $1 billion ($0.5–$1.6 billion) in pollution of private drinking water wells." Results also showed a disconnect between those reaping economic rewards from fracking and those paying the price: the "benefits" (mostly in the form of lower natural gas prices to residential, commercial, and industrial consumers) were geographically dispersed while the costs tended to concentrate in localized areas where drilling took place. Although the most comprehensive economic study to date, this analysis was not able to fully quantify all costs, including those related to water contamination (beyond surface-spill related costs for damage to private wells); diminishment of open spaces and aesthetics for community members; and seismic activity. The authors concluded that costs might well outweigh the benefits for suburban dwellers near fracking operations, as exemplified by Denton, Texas, where "nearly all the royalty money was flowing to mineral owners living elsewhere…rather than to adjacent homeowners."[931]

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[929] Englert, E. (2017, August 10). Fracking brings challenges to local school systems. *U.S. News and World Report.* Retrieved from https://www.usnews.com/news/national-news/articles/2017-08-10/fracking-brings-challenges-to-local-school-systems

[930] The Academy of Medicine, Engineering and Science of Texas. (2017. *Environmental and Community Impacts of Shale Development in Texas.* Retrieved from http://tamest.org/shale-task-force/
doi: 10.25238/TAMESTstf.6.2017

[931] Loomis, J., & Haefele, M. (2017). Quantifying market and non-market benefits and costs of hydraulic fracturing in the United States: A summary of the literature. *Ecological Economics, 138,* 160-167. doi: 10.1016/j.ecolecon.2017.03.036

- February 19, 2017 – The *New York Times* reported on the oil and gas industry's embrace of automation and its threat to preserving and bringing back jobs. Executives interviewed as part of the investigation were straightforward in their intentions to shrink their work forces. "'We want to transform our work force to the point where we need to hire fewer people,' said Joey Hall, Pioneer's executive vice president for Permian Operations." In 2016 Pioneer Natural Resources added 240 wells in West Texas without adding any new employees. A vice president at a Pennsylvania manufacturer of drilling rigs stated, "If it's a repetitive task, it can be automated, and I don't need someone to do that. I can get a computer to do that."[932]

- February 1, 2017 – Stanford University earth science professor Robert Jackson and two professors of law assessed how a new type of "conservation easement," an established kind of legal agreement, could enable landowners to restrict fracking on their properties. A mineral estate conservation easement (MECE) can serve as a private landowner response to the demonstrable threats of fracking to property and community: "Accompanying the rise of high-volume hydraulic fracturing has been a suite of environmental and social concerns, including potential water and air contamination, greenhouse gas emissions, health effects, and community disruptions." "We support the exploration of MECEs as an additional tool for landowners to exercise their rights and responsibilities," the team concluded.[933]

- January 26, 2017 – Automation is reducing the size of drilling crews and will lessen the number of jobs added nationally with any upturn in oil and gas operations, according to a piece on OilPrice.com. The author described predictions, including:

  > Automated drilling rigs may be able in the future to reduce the number of persons in a drilling crew by almost 40 percent, from 25 workers to 15 workers, *Houston Chronicle*'s Jordan Blum writes, quoting industry analysts.
  >
  > Drilling company Nabors Industries expects that it may be able to reduce the size of the crew at each well site to around 5 people from 20 workers now if more automated drilling rigs are used, Bloomberg's David Wethe says.[934]

- December 22, 2016 – Researchers with the Energy Policy Institute at the University of Chicago measured the costs and benefits of fracking in local communities across nine U.S. shale basins. They found that, despite contributions to local economies with the

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[932] Krauss, C. (2017, Feburary 19). Texas oil fields rebound from price lull, but jobs are left behind. *New York Times*. Retrieved from https://www.nytimes.com/2017/02/19/business/energy-environment/oil-jobs-technology.html?_r=0

[933] Jackson, R. B., Owley, J., & Salzman, J. (2017). Mineral estate conservation easements: A new policy instrument to address hydraulic fracturing and resource extraction. *Environmental Law Reporter*, *47*(2). 10112-10120. Retrieved from https://elr.info/news-analysis/47/10112/mineral-estate-conservation-easements-new-policy-instrument-address-hydraulic-fracturing-and-resource-ext

[934] Paraskova, T. (2017, January 26). Robots over roughnecks: Next drilling boom might not add many jobs. *OilPrice.com.* Retrieved from https://oilprice.com/Energy/Energy-General/Robots-Over-Roughnecks-Next-Drilling-Boom-Might-Not-Add-Many-Jobs.html

arrival of fracking, residents experienced decreases in local quality of life. Spikes in crime were the most directly measurable of these effects. "Despite local governments' efforts to improve public safety—allocating 20 percent more funding—the crime rates still marginally increased." The study also found unequal distribution of benefits. Students, the elderly, and those who don't own mineral rights did not benefit at all. Their analysis found an average gain of about $1,300 to $1,900 per household per year, but these gains were offset by a reduction in the typical household's quality of life, which the authors computed at about $1,000 to $1,600 per year.[935]

- December 21, 2016 – Economists from the University of Anchorage and Montana State University studied the impact of regional shale energy booms on crime rates across U.S. counties from 2000 to 2013, documenting increased rates of many types of crime, including assault, rape, larceny, and auto theft. In 2013, they pegged the average monetary cost of these additional crimes at $2 million per county. Researchers emphasized these results represented short-term costs only, as they could not predict how crimes rates and attendant costs will accrue over longer periods of time, as, for example, if criminal behavior and labor migration facilitate a slow drain of human and physical capital from the region and propagate "a long-term resource curse." The study also found "that registered sex offenders moved in disproportionate numbers to boom towns in North Dakota," and "that income inequality increased as the shale boom progressed."[936]

- May 24, 2016 – In 327 U.S. counties previously at the center of the fracking boom, overdue car loans approached their highest level in five years, and late mortgage payments also rose, according to a report by the *Financial Times* that examined data from the Federal Reserve Bank of New York. These trends stood in stark contrast to lowered overdue debt rates in the rest of the U.S. This surge in late car payments in intensely fracked areas of the United States has "exposed the damage done by the collapse in drilling activity and marred broadly positive trends for late debt payments by American consumers."[937]

- May 8, 2016 – With the downturn in the fracking industry, Wisconsin's sand mining sector, which provides silica sand for fracking operations, has also slumped and prompted significant layoffs and job losses in both 2015 and 2016, according to a report by Eau Claire's *Leader-Telegram*. "This is what the bust part of the boom-and-bust cycle of the energy sector looks like, and it's something west-central Wisconsin residents, who are mostly new to the industry, aren't used to seeing." Other companies that supply goods and services to sand mining operations in the region have also experienced a downturn.[938]

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[935] Bartik, A. W., Currie, J., Greenstone, M., & Knittel, C. R. (2016). *The local economic and welfare consequences of hydraulic fracturing.* Energy Policy Institute at the University of Chicago. Retrieved from https://epic.uchicago.edu/research/publications/local-economic-and-welfare-consequences-hydraulic-fracturing
[936] James, A., & Smith, B. (2016). There will be blood: Crime rates in shale-rich U.S.counties. *Journal of Environmental Economics and Management, 84,* 125–152. doi: 10.1016/j.jeem.2016.12.004
[937] Fleming, S. (2016, May 24). US fracking bust sparks surge in car debt. *Financial Times.* Retrieved from http://www.ft.com/cms/s/0/a4cb1270-21c2-11e6-aa98-db1e01fabc0c.html
[938] Lindquist, E. (2016, May 8). Silent sandbox: Once booming frac sand industry continues major downturn. *Leader-Telegram.* Retrieved from http://www.leadertelegram.com/News/Front-Page/2016/05/08/Silentsandbox.html

- March 8, 2016 – A DeWitt County, Texas judge estimated it will cost his county $432 million to rebuild its roads, noting that if a road "leads to a rig site, it's bound to be a broken road." The judge stated that ultimately the companies would pay a large share.[939]

- February 22, 2016 – *Inside Energy* investigated oil-industry related wage theft claims in the West, finding "a growing number of oil workers are turning to the courts, saying they weren't paid fairly even when times were good." Between 2010 and 2015, wage theft suits against oil and gas companies in Colorado increased by a factor of nine, and in Texas nearly ten times. The investigation found that oil and gas companies were consistently among the top violators of wage laws—especially in failure to pay overtime. A federal investigation of the industry led to the recovery of $40 million dollars in unpaid wages. One of the officers involved in the investigations is quoted saying, "We have found cases where workers were not even paid the minimum wage, because they're working so many hours…. So the idea that they're being highly compensated, in some cases, they're not."[940]

- January 13, 2016 – A fire on a fracking site in Grady County, Oklahoma that consumed 22 oil tankers required the response of six regional fire departments.[941]

- December 15, 2015 – The value of homes that rely on well water in Pennsylvania dropped an average of $30,167 when fracking took place within 1.5 kilometers, according to a study by Duke University researchers published in the *American Economic Review*. For these groundwater-dependent homes, a fracking well located within one kilometer was linked to a 13.9 percent average decrease in values; homes with wells at least two kilometers away maintained their value. The study was based on home sales between 1995 and 2012 in 36 counties. Researchers stated that their figures may not fully reflect the total costs associated with groundwater contamination risk, as, for example, when homeowners purchase expensive home water filtration systems. Though their study does not incorporate data on actual contamination, concerns about contamination can significantly affect property values. Researchers found "strong evidence of localized costs borne particularly by groundwater-dependent homes."[942]

- December 8, 2015 – Even as housing prices in shale gas-areas of Pennsylvania have dropped along with fracking activity, many seniors and people living on low incomes are still being priced out of the market, *StateImpact* reported. Pennsylvania still lacks a quarter million affordable rental homes for people in poverty despite a 2012 law

[939] Callahan, C. (2016, March 8). Fracking fall-off leaves South Texas roads a mess. *KSAT.com*. Retrieved from http://www.ksat.com/web/ksat/news/fracking-fall-off-leaves-south-texas-roads-a-mess
[940] Boyce, D. (2016, February 22). Wage theft claims surge as oil prices fall. *Inside Energy.* Retrieved from http://insideenergy.org/2016/02/22/wage-theft-claims-surge-as-oil-prices-fall/
[941] KFOR-TV, Querry, K., & Fultonberg, L. (2016, January 13). Firefighters extinguish damaging Grady Co. fracking fire. *KFOR.com*. Retrieved from http://kfor.com/2016/01/13/all-lanes-of-traffic-shut-down-due-to-large-oil-rig-fire/
[942] Muehlenbachs, L., Spiller, E., & Timmins, C. (2015). The housing market impacts of shale gas development. *American Economic Review*, *105*(12), 3633–3659. doi: 10.1257/aer.20140079

requiring gas companies to pay well fees intended to offset the costs of affordable housing programs in communities where drilling is occurring.[943]

- December 2, 2015 – "The local economy is feeling the pinch" of the downturn of activity in Pennsylvania's gas fields, according to a Reuters report. The late 2015 slump marked a turning point in Marcellus Shale fracking. Regional economic effects reported include empty hotel rooms and foreclosure notices in Lycoming County at their highest since data were first collected.[944]

- October 7, 2015 – Vehicular collisions and Texas fracking activity are closely linked, according to a report by the Texas A&M University Transportation Institute. Researchers analyzed the number of crashes and injuries across Texas during the period from 2006 to 2009, when drilling and fracking operations were intensive over the Barnett Shale, as well as from 2010 to 2013, when activity increased in the Permian Basin in West Texas and the Eagle Ford Shale in South Texas, and decreased in the Barnett. Collisions increased where shale gas activity increased and decreased where it slowed down.[945] Quoted in the *Texas Tribune*, report co-author Cesar Quiroga said, "The two trends correlated so well, and they were perfectly aligned ….We could use this as a predictive model."[946] Further, the increase was greater in South Texas, the region that relies most heavily on horizontal, hydraulic fracking requiring millions of gallons of water and sand to be trucked in, compared to West Texas which does use fracking but also more simple, vertical wells. The comprehensive cost of these collisions was estimated to be about $2 billion more from 2010 to 2013—in both the Eagle Ford and Permian Basin—compared to the previous period.

- September 30, 2015 – The North Dakota Bureau of Criminal Investigation was set to hire nine new agents, reported the *Billings Gazette*, "…allowing for more attention to cases of human trafficking and organized crime in western North Dakota … as increased oil production resulted in growing populations."[947]

- September 29, 2015 – "New residential units sit empty as gas production falls," *HousingWire Magazine* wrote, following up on their earlier reporting describing the link between the drilling boom and the real estate boom in the Bakken shale region of North

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[943] Cusick, M. (2015, December 8). Despite drilling slowdown, rents still high in fracking boomtowns. *StateImpact.* Retrieved from https://stateimpact.npr.org/pennsylvania/2015/12/08/despite-drilling-slowdown-rents-still-high-in-fracking-boomtowns/
[944] McAllister, E. (2015, December 2). America's biggest gas field finally succumbs to downturn. *Reuters.com*. Retrieved from http://www.reuters.com/article/us-usa-marcellus-decline-insight-idUSKBN0TL0CY20151202#W0DRBI8eM4MKscSV.97
[945] Quiroga, C. & Tsapakis, J. (2015). *Oil and gas energy developments and changes in crash trends in Texas.* Texas A&M Transportation Institute, PRC 15-35 F. Retrieved from http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/PRC-15-35-F.pdf
[946] Malewitz, J. (2015, October 7). Report: Energy boom-related traffic crashes cost billions. *Texas Tribune*. Retrieved from https://www.texastribune.org/2015/10/07/report-shows-huge-toll-energy-boom-traffic-crashes/
[947] McCleary, M. (2016, September 30). North Dakota to hire 9 more criminal investigation agents. *Billings Gazette*. Retrieved from http://billingsgazette.com/news/state-and-regional/montana/north-dakota-to-hire-more-criminal-investigation-agents/article_a4192344-c9b0-51cc-9693-5a4335f5be05.html

Dakota. Economic data indicate that Bakken drilling is not lasting long enough to sustain the building explosion.[948]

- September 9, 2015 – Most local governments in Western North Dakota and Eastern Montana's Bakken region have experienced net negative fiscal effects, according to a Duke University analysis published by the National Bureau of Economic Research. These trends were also seen in municipalities in rural Colorado and Wyoming, which also struggled to manage fiscal impacts during recent oil and gas booms, but in these two states the fiscal impact eased as drilling activity slowed.[949] Referencing the report, *McClatchyDC* wrote, "North Dakota cities and counties have been slammed." Municipal challenges have included providing water and sewer infrastructure, substantial damage to roads, soaring housing prices, and strained emergency services.[950]

- August 27, 2015 – Fracking in or near public parks could cause tourists to stay away and lead to a decline in park use, according to a report published by a team of tourism, recreation, and sport management researchers from the University of Florida, North Carolina State University, and Florida State University. Using data collected from 225 self-identified park users from Pennsylvania, Ohio, West Virginia, Kentucky, and Tennessee, researchers reported that only one-third of participants were willing to participate in recreational activities near fracking operations, compared to 38 percent unwilling, and 29 percent neutral. Forty-six percent of respondents supported a ban on fracking on public lands, while 20 percent agreed with promoting fracking on public lands.[951]

- July 1, 2015 – Britain's Department for Environment, Food & Rural Affairs released previously redacted sections of a report on the impacts of drilling and fracking. The report found that housing prices near fracking wells would likely fall up to seven percent for houses within a mile of wells. Furthermore, properties within one to five miles of fracking sites could incur additional insurance costs. The report warned of environmental damages, including from leakage of fracking waste fluids, and found that public health could be affected indirectly through consumption of contaminated wildlife, livestock, or agricultural products. The report also found potential for some benefits, such as job growth.[952]

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[948] Lane, N. (2015, September 29). Is fracking about to bust housing in North Dakota? *HousingWire Magazine.* Retrieved from http://www.housingwire.com/articles/35196-is-fracking-about-to-bust-housing-in-north-dakota
[949] Newell, R. G., & Raimi, D. (2015). *Shale public finance: Local government revenues and costs associated with oil and gas development.* The National Bureau of Economic Research, Working Paper No. 21542. doi: 10.3386/w21542
[950] Cockerham, S. (2015, September 9). Oil boom a loser for North Dakota cities, counties, study finds. *McClatchyDC.* Retrieved from http://www.mcclatchydc.com/news/nation-world/national/economy/article34552824.html
[951] Kellison, T. B., Bunds, K. S., Casper, J. M., & Newman, J. I. (2015). Fracking & parkland: Understanding the impact of hydraulic fracturing on public park usage. Retrieved from http://plaza.ufl.edu/tkellison/_/Fracking.html
[952] Vaughan, A. & Mason, R. (2015, July 1). Fracking could hurt house prices, health and environment, official report says. *Guardian*. Retrieved from http://www.theguardian.com/environment/2015/jul/01/fracking-could-hurt-house-prices-health-and-environment-official-report-says

- July 2015 – A working paper by researchers with the National Bureau of Economic Research found that fracking resulted in an increase in male teen high school dropout rates. "Our estimates imply that, absent fracking, the male-female gap in high school dropout rates among 17- 18-year olds would have narrowed by about 11 percent between 2000 and 2013 instead of remaining unchanged." The authors explained that by increasing the demand for low-skilled labor, fracking could slow growth in educational attainment. They noted that the relative wage boost from fracking may be only temporary. Indeed, by the end of the sample period, the benefits had started to wane as the labor demand from fracking appeared to no longer favor dropouts. Thus, the fracking boom may be inhibiting educational achievement among young men who "would already be near the bottom of the skill distribution, with possible implications for future productivity and the social safety net."[953, 954]

- March 20, 2015 – The U.S. Attorney for Western New York linked a rise in production of methamphetamine to use among workers in the fracking fields of northern and western Pennsylvania. Surging demand for the drug, which allows users to stay awake for 48 to 72 hours, may be related to the extremely long working hours that employees in the gas industry must endure.[955]

- January 4, 2015 – A documentary by Forum News Service, "Trafficked Report," revealed that sex trafficking, including of children, in the Bakken oil fields of North Dakota was a significant problem.[956] The dynamics of the oil boom, with an influx of out-of-state and primarily male workers far from their families, created an increase in demand for prostitution.[957]

- December 28, 2014 – The *New York Times* profiled the impacts of oil drilling and fracking on the Fort Berthold Indian Reservation in North Dakota, finding corruption, crime, and negative environmental impacts. Aside from a significant rise in jobs, which often go to transient workers, many residents "see deterioration rather than improvement in their standard of living. They endure intense truck traffic, degraded roads, increased crime, strained services and the pollution from spills, flares and illegal dumping." According to the *Times*' calculation, the reservation had seen 850 oil-related

[953] Cascio, F. U., & Narayan, A. (2015, July). Who Needs a Fracking Education? The Educational Response to Low-Skill Biased Technological Change. National Bureau of Economic Research. Retrieved from http://www.nber.org/papers/w21359
[954] Chandra, S. (2015, July 14). Fracking jobs encouraged American teens to become high school dropouts. *Bloomberg Business*. Retrieved from: http://www.bloomberg.com/news/articles/2015-07-14/fracking-jobs-encouraged-american-teens-to-become-high-school-dropouts
[955] Newberg, R. (2015, March 20). Meth use tied to fracking workers in Pennsylvania. *WIVB 4*. Retrieved from http://wivb.com/2015/03/20/meth-use-tied-to-fracking-workers-in-pennsylvania/
[956] Dalrymple, A. & Lymn, K. (2015, January 4). Trafficked Report: Sex for sale in the Bakken. *Forum News Service*. Retrieved from http://www.traffickedreport.com/?p=15
[957] Gaines, J. (2015, March 9). The oil boom in North Dakota now has a serious sex-trafficking problem. *Business Insider*. Retrieved from http://www.businessinsider.com/north-dakota-sex-trafficking-prostitution-oil-boom-police-raid-2015-3

environmental incidents from 2007 through mid-October 2014, which generally went unpunished.[958]

- December 26, 2014 – Examining Pennsylvania Department of Transportation data, Ohio's *Star Beacon* newspaper found that fracking poses a safety threat on rural roads. The paper found that Pennsylvania's five busiest drilling counties recorded 123 more heavy truck crashes in 2011 than before the gas boom began—a 107 percent increase. The paper noted the burden drilling and fracking placed on local communities and governments, including the strain on local emergency responders.[959]

- December 17, 2014 – Heavy drilling and fracking (defined as 400 or more wells drilled within a county over 5-8 years) was positively correlated with increased crime, sexually transmitted diseases, and traffic fatalities, according to a report by the Multi-State Shale Research Collaborative.[960] The report looked at the impacts in Pennsylvania, Ohio, and West Virginia, primarily finding statistically significant impacts in six heavily drilled counties in Pennsylvania. In those six counties, violent crime increased 17.7 percent—corresponding to about 130 more violent crimes in those counties in 2012—compared to a decrease in violent crime rates in both urban and rural non-drilling communities. Property crime increased 10.8 percent in those six counties, drug abuse rates rose 48 percent, and drunk-driving offenses rose 65 percent compared to 42 percent in rural areas with no drilling. The report found a statistically significant increase of 24 percent to 27 percent in rates of sexually transmitted diseases across drilling counties in all three states. Motor vehicle fatalities increased 27.8 percent in Pennsylvania's six high-drilling counties. The report found a modest increase in jobs, but noted that an influx of out-of-state workers at least partially explained the increases in traffic and crime.[961]

- December 15, 2014 – A report written in French by Quebec's Advisory Office of Environmental Hearings concluded that the environmental costs of fracking in the St. Lawrence Lowlands would outweigh the potential economic benefits. In a press release, the Advisory Office of Environmental Hearings concluded that fracking "would not be advantageous for Quebec because of the magnitude of the potential costs and externalities, compared to royalties that would be collected by Quebec. Other concerns

[958] Sontag, D. & McDonald B. (2014, December 28). In North Dakota, a tale of oil, corruption and death. *The New York Times*. Retrieved from http://www.nytimes.com/2014/12/29/us/in-north-dakota-where-oil-corruption-and-bodies-surface.html
[959] Finnerty, J. (2014, December 26). Fracking's biggest safety threat is on rural roads. *Star Beacon*. Retrieved from http://www.starbeacon.com/news/fracking-s-biggest-safety-threat-is-on-rural-roads/article_bc48687a-8caf-11e4-b4d9-6382c924a6f9.html
[960] Price, M., Herzenberg, S., Ward, S., Wazeter, E., & Basurto, L. E. (2014, December). *The Shale Tipping Point: The Relationship of Drilling to Crime, Traffic Fatalities, STDs, and Rents in Pennsylvania, West Virginia, and Ohio.* Retrieved from: http://www.multistateshale.org/shale-tipping-point
[961] McKelvey, W. (2014, December 17). Fracking brought spikes in crime, road deaths and STDs to Pa.: report. *Patriot News*. Retrieved from http://www.pennlive.com/midstate/index.ssf/2014/12/fracking_brought_spikes_in_vio.html

also remain, including plans of social acceptability, legislation, and a lack of knowledge, particularly with respect to water resources."[962]

- October 30, 2014 – The *New York Times* profiled the profound impact heavy drilling has had on Glasscock County, Texas, including its farming community. Farmers described increases in trash, traffic accidents, clashes around farmers selling groundwater to drillers, and economic detriment. In many cases, acres of farmland around a drill site "will probably never be suitable for fertile farming again," and farmers are "at the mercy" of what drillers want to pay for damages. The county itself receives revenue, but most of that additional money "is being used to repair roads damaged by oil field truck activity. Overall, the gains from drilling are not viewed as worth the drawbacks in a county long dominated by cotton farming."[963]

- September 28, 2014 – A *Washington Post* investigation reported on heroin and methamphetamine addiction—and associated violent crime—among Native American communities located within the Bakken Shale oil fields. According to a chief judge for the Mandan, Hidatsa, and Arikara Nation, "The drug problem that the oil boom has brought is destroying our reservation."[964]

- September 11, 2014 – An editor for the *Washington Post* examined jobs and manufacturing data in Youngstown, Ohio, to demonstrate that drilling and fracking are not resulting in a revitalization of the Rust Belt as some proponents and a prominent *New York Times* story asserted. The *Post* determined that in Youngstown, Ohio, the manufacturing sector has lost jobs by the tens of thousands in the last twenty years and the oil and gas industry has created approximately two thousand jobs since the recession ended. Six years prior, there were 13,000 more jobs in the Youngstown metro area than there were in summer 2014.[965]

- September 9, 2014 – A study by researchers at Colorado State University examined the political economy of harm and crime associated with the oil and gas industry in rural Colorado, particularly around the rise of fracking. The researchers looked at complaints that citizens filed with the state, and also conducted interviews and examined other data. They found 2,444 complaints between November 2001 and June 2013 covering a range of issues including water, environment, noise, air quality, land use, and more. They characterized citizen complaints as "extensive and complex" and concluded that,

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[962] McCarthy, S. (2014, December 15). Fracking dealt another setback by Quebec report. *Globe and Mail.* Retrieved from http://www.theglobeandmail.com/report-on-business/industry-news/energy-and-resources/bape-says-shale-gas-production-not-advantageous-for-quebec/article22096203/
[963] Batheja, A. (2014, October 30). A county resents oil drilling, despite the money it brings in. *The New York Times*. Retrieved from http://www.nytimes.com/2014/10/31/us/a-county-resents-oil-drilling-despite-the-money-it-brings-in.html?ref=earth&_r=1
[964] Horwitz, S. (2014, September 28). Dark side of the boom: North Dakota's oil rush brings cash and promise to reservation along with drug-fueled crime. *The Washington Post.* Retrieved from http://www.washingtonpost.com/sf/national/2014/09/28/dark-side-of-the-boom/
[965] Tankersley, J. (2014, September 11). Fracking hasn't restored the Rust Belt's lost jobs. *The Washington Post*. Retrieved from http://www.washingtonpost.com/news/storyline/wp/2014/09/11/fracking-hasnt-restored-the-rust-belts-lost-jobs/

regardless of the nature of the harm, most were "persistent and omnipresent" rather than short-lived, isolated problems.[966]

- September 6, 2014 – In Williams County, North Dakota, in the Bakken Shale, increases in crime have corresponded with the flow of oil. The infusion of cash has attracted career criminals who deal in drugs, violence, and human sex trafficking. The *Williston Herald* portrayed, in a "reader's discretion advised" article, the rapid rise of "index crimes"—"violent crimes that result in the immediate loss of an individual's property, health or safety, such as murder, larceny and rape." With fewer than 100 law enforcement personnel, crime in Williams County "has risen in kind with the county's population, but funding, staffing and support training for law enforcement has not."[967]

- September 2014 – Reporting on the social, environmental, health and safety, and economic burdens endured by localities from fracking, the magazine *Governing: The States and Localities* found that "fracking, in many cases, negatively impacts property values, which in turn depresses property tax revenue. For property owners who own the rights to the oil and gas on their land, the effects of drilling can be offset by royalty payments. But localities have no revenue offset if properties lose value."[968]

- August 26, 2014 – The U.S. Justice Department Office on Violence Against Women awarded three million dollars to five rural and tribal communities to prosecute crimes of violence against women and provide services to victims of sexual assault, domestic violence, and stalking in the Bakken Region of North Dakota and Montana.[969] Rationale documented by tribal leaders, law enforcement, and the FBI included, "rapid development of trailer parks and modular housing developments often referred to as 'man camps;' abrupt increase in cost of living, especially housing; rapid influx of people, including transients, in a previously rural and stable community; constant fear and perception of danger; and a lost way of life. Local and tribal officials and service providers reported that these changes have been accompanied by a rise in crime, including domestic and sexual violence."[970]

- May 27, 2014 – A *Bloomberg News* analysis of 61 shale-drilling companies found that the economic picture of shale oil and gas is unstable. Shale debt has almost doubled over the last four years while revenue has gained just 5.6 percent. For the 61 companies in

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[966] Opsal, T., & Shelley T. O. (2014). Energy crime, harm, and problematic state response in Colorado: A case of the fox guarding the hen house? *Critical Criminology, 22* (4), 561-577.
[967] Bell, T. (2014, September 6). Modernized slavery. *Williston Herald.* Retrieved from http://www.willistonherald.com/news/modernized-slavery/article_84e257d8-3615-11e4-a4f8-001a4bcf887a.html
[968] Shafroth, F. (2014, September). Fracking's financial losers: local governments. *Governing: The States and Localities.* Retrieved from http://www.governing.com/columns/public-money/gov-frackings-financial-losers.html
[969] U.S. Department of Justice. (2014, August 26). Associate Attorney General West announces $3 million in grants to address violence against women in rural and tribal communities in the Bakken Region. *Justice News*. Retrieved from http://www.justice.gov/opa/pr/associate-attorney-general-west-announces-3-million-grants-address-violence-against-women
[970] U.S. Department of Justice. (2014). OVW Fiscal Year 2014 Violence Against Women Bakken Region Initiative: Enhanced response to victims application guidelines. Retrieved from http://www.justice.gov/sites/default/files/ovw/legacy/2014/04/25/fy2014-initative-for-the-bakken-region-enhanced-services-for-victims.pdf

their analysis, *Bloomberg News* reported: "In a measure of the shale industry's financial burden, debt hit $163.6 billion in the first quarter." Further, *Bloomberg* noted that drillers are caught in a bind because they must keep borrowing to pay for exploration needed to "offset steep production declines typical of shale wells…. For companies that can't afford to keep drilling, less oil coming out means less money coming in, accelerating the financial tailspin."[971]

- May 5, 2014 – An Associated Press analysis found that traffic fatalities have spiked in heavily drilled areas of six states, whereas most other roads in the nation have become safer even as population has grown. In North Dakota drilling counties, for instance, traffic fatalities have increased 350 percent.[972]

- April 16, 2014 – A comprehensive article in the *Albany Law Review* concluded that the risks inherent with fracking are not covered by homeowner's insurance, not fully insured by the oil and gas industry, and threaten mortgages and property value.[973]

- April 2014 – A report by the Multi-State Shale Research Collaborative, "Assessing the Impacts of Shale Drilling: Four Community Case Studies," documented economic, community, government, and human services impact of fracking on four rural communities. The study found that fracking led to a rapid influx of out-of-state workers and, although some new jobs were created, these were accompanied by additional costs for police, emergency services, road damage, and social services. In addition, increased rents, and a shortage of affordable housing accompanied the fracking boom. Unemployment rose after one county's boom ended; in another county, unemployment stayed above the state average throughout.[974]

- March 27, 2014 – A report by researchers at Rand Corporation determined that each shale gas well in Pennsylvania causes between $5,400 and $10,000 in damage to state roads. The report did not calculate damage to local roads, which is also significant. Researchers used estimates of truck trips that are significantly below the number

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971 Loder, A. (2014, May 27). Shakeout threatens shale patch as frackers go for broke. *Bloomberg*. Retrieved from http://www.bloomberg.com/news/2014-05-26/shakeout-threatens-shale-patch-as-frackers-go-for-broke.html
972 Begos, K., & Fahey, J. (2014, May 5). AP impact: Deadly side effect to fracking boom. *Associated Press*. Retrieved from http://bigstory.ap.org/article/ap-impact-deadly-side-effect-fracking-boom-0
973 Radow, E. L. (2014). At the intersection of Wall Street and Main: Impacts of hydraulic fracturing on residential property interests, risk allocation, and implications for the secondary mortgage market. *Albany Law Review, 77*(2), 673-704.
974 Multi-State Shale Research Collaborative. (2014, April 10). *Assessing the impacts of shale drilling county case studies* (Rep.). Retrieved from https://docs.google.com/viewer?a=v&pid=sites&srcid=ZGVmYXVsdGRvbWFpbnxtdWx0aXN0YXRlc2hhbGV8Z3g6NGU4MjIyNWU5ZjFhZjM4Yg

estimated for New York by the New York State Department of Environmental Conservation (NYS DEC).[975, 976]

- February 15, 2014 – The *Los Angeles Times* detailed steep increases in crime that have accompanied fracking in parts of the Eagle Ford Shale in Texas, including sexual assaults and thefts.[977]

- February 14, 2014 – Pennsylvania landowners with fracking leases rallied in Bradford County against gas companies for precipitous drops in royalty payments.[978]

- December 20, 2013 – The National Association of Realtors' *RealtorMag* summarized a growing body of research, including a University of Denver survey and a *Reuters* analysis, that shows threats property values from fracking and gas drilling.[979]

- December 12, 2013 – A *Reuters* analysis discussed how oil and gas drilling has made making some properties "unsellable" and researched the link between drilling and property value declines. The analysis highlighted a Duke University working paper that finds shale gas drilling near homes can decrease property values by an average of 16.7 percent if the house depends on well water.[980]

- December 10, 2013 – Pennsylvania's *Daily Review* reported that more gas companies are shifting costs to leaseholders and that royalty payments are drastically shrinking. The story quoted Bradford County Commissioner Doug McLinko saying that some gas companies "are robbing our landowners" and that the problem of royalty payments being significantly reduced by deductions for post-production costs "is widespread throughout our county."[981]

- November 30, 2013 – The *New York Times* reported striking increases in crime in Montana and North Dakota where the oil and gas boom is prevalent, as well as challenges faced by local residents from the influx of out-of-area workers and the accompanying costs. The *New York Times* reported, "'It just feels like the modern-day Wild West,' said

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975 Cusick, M. (2014, March 27). Report finds each Marcellus gas well costs thousands in road damage. *StateImpact*. Retrieved from http://stateimpact.npr.org/pennsylvania/2014/03/27/report-finds-each-marcellus-gas-well-costs-thousands-in-road-damage/

976 Abramzon, S., Samaras, C., Curtright, A., Litovitz, A., & Burger, N. (2014). Estimating the consumptive use costs of shale natural gas extraction on Pennsylvania roadways. *Journal of Infrastructure Systems*. *20*(3). doi: 10.1061/(ASCE)IS.1943-555X.0000203, 06014001

977 Hennessy-Fiske, M. (2014, February 15). Fracking brings oil boom to south Texas town, for a price. Retrieved from http://www.latimes.com/nation/la-na-texas-oil-boom-20140216%2C0%2C7621618.story#ixzz30Iw9FXoz.

978 Marshall, J. (2014, February 14). Landowners rally for royalties from gas companies. Retrieved from http://www.wbng.com/news/local/Landowners-rally-for-245596511.html

979 Daily Real Estate News. (2013, December 20). 'Fracking' sparks concern over nearby home values. *National Association of Realtors*. Retrieved, from http://realtormag.realtor.org/daily-news/2013/12/20/fracking-sparks-concern-over-nearby-home-values#.UrmdIlPmVu8.twitter

980 Conlin, M. (2013, December 12). Gas drilling is killing property values for some Americans. *Reuters*. Retrieved from http://www.businessinsider.com/drilling-can-make-some-properties-unsellable-2013-12#ixzz2nMgFv8FU

981 Loewenstein, J. (2013, December 10). Shrinking royalty checks. *Thedailyreview.com*. Retrieved from http://thedailyreview.com/news/shrinking-royalty-checks-1.1598195

Sgt. Kylan Klauzer, an investigator in Dickinson, in western North Dakota. The Dickinson police handled 41 violent crimes last year, up from seven only five years ago."[982]

- November 21, 2013 – The Multi-State Shale Research Collaborative released a six-state collaborative report demonstrating that the oil and gas industry has greatly exaggerated the number of jobs created by drilling and fracking in shale formations. The report found that far from the industry's claims of 31 direct jobs created per well, only four jobs are created for each well. It also demonstrated that almost all of the hundreds of thousands of 'ancillary' jobs that the drilling industry claims are related to shale drilling existed before such drilling occurred. As Frank Mauro, Executive Director Emeritus of the Fiscal Policy Institute put it, "Industry supporters have exaggerated the jobs impact in order to minimize or avoid altogether taxation, regulation, and even careful examination of shale drilling."[983]

- November 12, 2013 – *The American Banker* reported that the "Fracking Boom Gives Banks Mortgage Headaches," with a number of financial institutions refusing to make mortgages on land where oil and gas rights have been sold to an energy company. The article stated that the uniform New York state mortgage agreement used by Fannie Mae and Freddie Mac requires that homeowners not permit any hazardous materials to be used or located on their property. Fracking is therefore a problem because it is just such a hazardous activity with use of hazardous materials.[984]

- September 25, 2013 – A report found that fracking is linked to significant road damage, increased truck traffic, crime, and strain on municipal and social services. Data from the past ten years on the social costs of fracking including truck accidents, arrests, and higher rates of sexually transmitted diseases are all causes for alarm.[985]

- September 12, 2013 – In a feature titled "Pa. fracking boom goes bust," *The Philadelphia Inquirer* presented data from the independent Keystone Research Center detailing "flat at best" job growth and declines in production and royalty payments.[986]

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[982] Healy, J. (2013, November 30). As oil floods plains towns, crime pours in. *The New York Times*. Retrieved from http://www.nytimes.com/2013/12/01/us/as-oil-floods-plains-towns-crime-pours-in.html?smid=tw-share&_r=0

[983] Campbell, J. (2013, November 21). Report: Industry-backed studies exaggerate fracking job estimates. *Politics on the Hudson*. Retrieved from http://polhudson.lohudblogs.com/2013/11/21/report-industry-backed-studies-exaggerate-fracking-job-estimates/

[984] Peters, A. (2013, November 12). Fracking boom gives banks mortgage headaches. *American Banker*. Retrieved from http://www.americanbanker.com/issues/178_218/fracking-boom-gives-banks-mortgage-headaches-1063561-1.html

[985] Gibbons, B. S. (2013, September 25). Environmental groups calculate social cost of natural gas boom. *The Times-Tribune*. Retrieved from http://thetimes-tribune.com/news/environmental-groups-calculate-social-cost-of-natural-gas-boom-1.1558186

[986] Bunch, W. (2013, September 12). Pa. fracking boom goes bust. *Philly.com*. Retrieved from http://articles.philly.com/2013-09-12/news/41974274_1_fracking-boom-penn-state-marcellus-center-marcellus-shale

- August 22, 2013 – A University of Denver study in the *Journal of Real Estate Literature* found a 5-15 percent reduction in bid value for homes near gas drilling sites.[987]

- August 21, 2013 – *The Atlantic Cities* and *MSN Money* reported that fracking operations may be damaging property values and may impair mortgages or the ability to obtain property insurance.[988, 989]

- August 13, 2013 – A *ProPublica* investigative analysis found that Chesapeake Energy is coping with its financial difficulties in Pennsylvania by shifting costs to landowners who are now receiving drastically reduced royalty payments.[990]

- August 4, 2013 – In a survey of West Virginia landowners with shale wells on their property, more than half reported problems including damage to the land, decline in property values, truck traffic, and lack of compensation by the oil and gas company.[991]

- May 24, 2013 – Pennsylvania Department of Transportation Secretary Allen D. Biuhler and Pennsylvania State Police Commissioner Frank Pawlowski said that gas drilling has led to increases in truck traffic, traffic violations, crime, demand for social services, and the number of miles of roads that are in need of repairs. They noted that drilling companies that committed to repairing roads have not kept pace with the roads they damage. Commissioner Pawlowski reported that 56 percent of 194 trucks checked were over the legal weight limit and 50 percent were also cited for safety violations.[992]

- May 4, 2013 – Pennsylvania's *Beaver County Times* asked, "What boom?" in pointing to Keystone Research Center data showing that the number of jobs numbers created by shale gas extraction do not add up to what the gas industry claims, noting that unemployment has increased and the state actually fell to 49th in the nation for job creation.[993]

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987 Downing, B. (2013, April 22). Survey says home values hurt by fracking at drill sites. *Ohio.com*. Retrieved from http://www.ohio.com/blogs/drilling/ohio-utica-shale-1.291290/survey-says-home-values-hurt-by-fracking-at-drill-sites-1.422838

988 Drouin, R. (2013, August 19). How the fracking boom could lead to a housing bust. *Citylab*. Retrieved from http://www.theatlanticcities.com/politics/2013/08/how-fracking-boom-could-lead-housing-bust/6588/

989 Notte, J. (2013, August 21). Fracking leaves property values tapped out. *MSN Money*. Retrieved from http://money.msn.com/now/post--fracking-leaves-property-values-tapped-out

990 Lustgarten, A. (2013, August 13). Unfair share: How oil and gas drillers avoid paying royalties. *ProPublica*. Retrieved from http://www.propublica.org/article/unfair-share-how-oil-and-gas-drillers-avoid-paying-royalties

991 Collins, A. R., & Nkansah, K. (2013, August 4). *Divided rights, expanded conflict: The impact of split estates in natural gas production* [Scholarly project]. Retrieved from http://ageconsearch.umn.edu/bitstream/150128/2/Collins_Nkahsah_Split%20estate.pdf

992 PR Newswire. (2014, May 24). Increased gas drilling activities bringing new challenges to local governments in Pennsylvania. *PR Newswire*. Retrieved from http://www.prnewswire.com/news-releases/increased-gas-drilling-activities-bringing-new-challenges-to-local-governments-in-pennsylvania-94774764.html

993 Morgan, R. (2013, May 4). Beaver County Times: What boom? Industry pundits claim thousands of jobs will be created, but numbers don't quite add up. *Keystone Research Center*. Retrieved from http://keystoneresearch.org/media-center/media-coverage/beaver-county-times-what-boom-industry-pundits-claim-thousands-jobs-will

- April 2, 2013 – The *New York Times* reported that manufacturing jobs resulting from an abundance of shale gas have not appeared. "The promised job gains, other than in the petrochemical industry, have been slow to materialize," The *New York Times* reported. The article suggested that increased automation has made it unlikely that manufacturers will add many jobs.[994]

- March 19, 2013 – The *Wall Street Journal* reported that the shale gas boom has not had a big impact on U.S. manufacturing because lower energy prices are only one factor in a company's decision on where to locate factories, and not always the most important factor. "Cheap energy flowing from the U.S. shale-gas boom is often touted as a 'game changer' for manufacturing," the *Journal* reported. "Despite the benefits of lower energy costs, however, the game hasn't changed for most American manufacturers."[995]

- February 2013 – A peer-reviewed analysis of industry-funded and independent studies on the economics of fracking found that it is unlikely that fracking will lead to long-term economic prosperity for communities. The analysis noted that shale gas development brings a number of negative externalities including the potential for water, air, and land contamination; negative impacts on public health; wear and tear on roads and other infrastructure; and costs to communities due to increased demand for services such as police, fire departments, emergency responders, and hospitals.[996]

- November 16, 2012 – A Duke University study showed a drop in home values near fracking for properties that rely on groundwater. [997]

- September 27, 2012 – The *New York Times* reported that the prospect of fracking has hindered home sales in the Catskills and raised concerns about drops in property values, according to real estate agents and would-be buyers.[998]

- August 17, 2012 – A study by the state agencies, the Montana All Threat Intelligence Center and the North Dakota State and Local Intelligence Center, found that crime rose by 32 percent since 2005 in communities at the center of the oil and gas boom.[999]

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[994] Schwartz, N. D. (2013, April 01). Rumors of a cheap-energy jobs boom remain just that. *The New York Times*. Retrieved from http://www.nytimes.com/2013/04/02/business/economy/rumors-of-a-cheap-energy-jobs-boom-remain-just-that.html?_r=0

[995] Hagerty, J. R. (2013, March 19). Shale-gas boom alone won't propel U.S. industry. *The Wall Street Journal*. Retrieved from http://online.wsj.com/news/articles/SB10001424127887324392804578362781776519720

[996] Barth, J. M. (2013). The Economic Impact of Shale Gas Development on State and Local Economies: Benefits, Costs, and Uncertainties. *NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy, 23*(1), 85-101. doi: 10.2190/NS.23.1.f

[997] Muoio, D. (2012, November 16). Duke researchers show dip in home value caused by nearby fracking. *The Chronicle*. Retrieved from http://www.dukechronicle.com/articles/2012/11/16/duke-researchers-show-dip-home-value-caused-nearby-fracking

[998] Navarro, M. (2012, September 27). Gas drilling jitters unsettle Catskills sales. *The New York Times*. Retrieved from http://www.nytimes.com/2012/09/30/realestate/fracking-fears-hurt-second-home-sales-in-catskills.html?pagewanted=1

[999] Montana All Threat Intelligence Center, & North Dakota State and Local Intelligence Center. (2012, August 17). *Impact of population growth on law enforcement in the Williston Basin region* (Rep.). Retrieved from http://www.ag.nd.gov/reports/JOINTPRODUCTFINAL.pdf

- October 30, 2011 – A comprehensive article in the *New York State Bar Association Journal* concluded that the risks inherent with fracking threaten mortgages.[1000]

- October 26, 2011 – The Associated Press reported that areas with significant fracking activity, including Pennsylvania, Wyoming North Dakota and Texas, are "seeing a sharp increase in drunken driving, bar fights and other hell-raising."[1001]

- October 19, 2011 – A *New York Times* investigation found that fracking can create conflicts with mortgages, and that "bankers are concerned because many leases allow drillers to operate in ways that violate rules in landowners' mortgages," and further that "[f]earful of just such a possibility, some banks have become reluctant to grant mortgages on properties leased for gas drilling. At least eight local or national banks do not typically issue mortgages on such properties, lenders say."[1002]

- September 7, 2011 – The NYS DEC estimated that 77 percent of the workforce on initial shale gas drilling projects would consist of transient workers from out of state. Not until the thirtieth year of shale gas development would 90 percent of the workforce be comprised of New York residents.[1003]

- August 15, 2011 – The *Pittsburgh Post-Gazette* reported that increases in crime followed the Pennsylvania gas drilling boom, noting, for instance, that drunken driving arrests in Bradford County were up 60 percent, DUI arrests were up 50 percent in Towanda, and criminal sentencing was up 35 percent in 2010.[1004]

- July 26, 2011 – A New York State Department of Transportation document estimated that fracking in New York could result in the need for road repairs and reconstruction costing $211 million to $378 million each year.[1005]

[1000] Radow, E. N. (2011). Homeowners and gas drilling leases: Boon or bust? *New York State Bar Association Journal, 83*(9). Retrieved from http://www.s-oacc.org/resources/NYSBA_Journal_nov-dec2011_lead_article_with_reprint_info.pdf

[1001] Levy, M. (2011, October 26). Towns see crime, carousing surge amid gas boom. *Associated Press*. Retrieved from http://news.yahoo.com/towns-see-crime-carousing-surge-amid-gas-boom-135643480.html

[1002] Urbina, I. (2011, October 19). A rush to sign leases for gas runs into mortgage restriction. *The New York Times*. Retrieved from http://www.nytimes.com/2011/10/20/us/rush-to-drill-for-gas-creates-mortgage-conflicts.html?_r=2&hp&

[1003] New York State Department of Environmental Conservation. (2011). *Supplemental generic environmental impact statement on the oil, gas and solution mining regulatory program, well permit issuance for horizontal drilling and high-volume hydraulic fracturing to develop the Marcellus shale and other low-permeability gas reservoirs* (6-233, 234, Rep.).

[1004] Needles, Z. (2011, August 15). Must crime follow Pennsylvania's gas drilling boom? *Pittsburgh Post-Gazette*. Retrieved from http://www.post-gazette.com/stories/business/legal/must-crime-follow-pennsylvanias-gas-drilling-boom-310373/

[1005] Reilly, S. (2011, July 26). Document estimates fracking's toll on N.Y. roads. *Pressconnects.com*. Retrieved from http://www.pressconnects.com/article/20110726/NEWS01/107260384/Document-estimates-fracking-s-toll-N-Y-roads

- June 20, 2011 – A Keystone Research Center study found that the gas industry's claim of 48,000 jobs created between 2007 and 2010 as a result of natural gas drilling in Pennsylvania is a far cry from the actual number of only 5,669 jobs—many of which were out-of-state hires.[1006]

- May 9, 2011 – A study in the *Journal of Town & City Management* found that shale gas development can impose "significant short- and long-term costs" to local communities. The study noted that shale gas development creates a wide range of potential environmental hazards and stressors, all of which can adversely impact regional economies, including tourism and agriculture sectors.[1007]

- November 30, 2010 – The *Dallas Morning News* featured a story, "Drilling Can Dig into Land Value," reporting that the Wise County Central Appraisal District Appraisal Review Board found that a drilling company had caused an "extraordinary reduction" in property value, by 75 percent.[1008]

- November 28, 2010 – The Texas *Wise County Messenger* reported that some landowners near fracking operations experience excessive noise, exposure to diesel fumes, and problems with trespassing by workers.[1009]

Inflated estimates of oil and gas reserves and profitability

Industry estimates of oil and gas reserves and profitability of drilling have proven unreliable, casting serious doubts on the bright economic prospects the industry has painted for the public, media, and investors. Increasingly, well production has been short-lived, which has led companies drilling shale to reduce the value of their assets by billions of dollars, creating shortfalls that are largely filled through asset sales and increasing debt load. Beginning in 2014, a fall in oil and gas prices led to a two-year downturn in fracking operations. As interest payments consumed the revenue of many smaller companies, more than 70 U.S. oil and gas companies declared bankruptcy, and the number of oil and gas rigs declined by 75 percent or more. When companies abandoned operations, they also abandoned the wells they drilled, raising questions about who serves as the custodian of inactive wells and their associated infrastructure, now and hereafter. In Alberta, Canada, newly abandoned wells dot the landscape, with many leaking methane, leaving the provincial government to close down and dismantle them—a task estimated to require decades of work.

[1006] Herzenberg, S. (2011). Drilling deeper into job claims. Keystone Research Center. Retrieved from http://keystoneresearch.org/sites/keystoneresearch.org/files/Drilling-Deeper-into-Jobs-Claims-6-20-2011_0.pdf

[1007] Christopherson, S. & Rightor, N. (2011). How shale gas extraction affects drilling localities: Lessons for regional and city policy makers. *Journal of Town & City Management, 2*(4), 1-20. Retrieved from http://www.greenchoices.cornell.edu/downloads/development/shale/Economic_Effects_on_Drilling_Localities.pdf

[1008] Heinkel-Wolfe, P. (2010, September 18). Drilling can dig into land value. *Dallas News*. Retrieved from http://www.dallasnews.com/incoming/20100918-Drilling-can-dig-into-land-value-9345.ece

[1009] Evans, B. (2010, November 28). Rising volume: 'Fracking' has bolstered economies, but noise still echoes around drilling. *WCMessenger.com*. Retrieved from http://www.wcmessenger.com/2010/news/rising-volume-fracking-has-bolstered-economies-but-noise-still-echoes-around-drilling/

In 2017, a modest recovery in prices brought renewed industry enthusiasm for fracking. However, because of the rapid depletion of individual shale wells and the falling output of major shale basins, including the Bakken and the Marcellus, operators must reinvest profits to drill new wells at an increasingly rapid pace just to maintain the same level of extraction. According to the U.S. Energy Information Administration, half of all U.S. oil is now produced by wells that are two years old or younger. The need to stabilize economic fundamentals by increasing production is contributing to the shift toward "mega-fracking," with ever-longer laterals to access more oil or gas—and with requirements for higher volumes of water, sand, and chemicals per well.

- June 16, 2017 – Because of a persistent slump in gas prices and the declining productivity of many of its Marcellus Shale wells, the revenue from gas drilling fees fell for a third straight year in Pennsylvania. The annual fee revenue goes to county and municipal governments, roadway repairs, and infrastructure upgrades, among other things.[1010]

- March 25, 2017 – The *Economist* took shale fracking to task for its unstable finances and inability to turn a profit. "Shale firms are on an unparalleled money-losing streak. About $11bn was torched in the last quarter, as capital expenditures exceeded cashflows. The cash-burn rate may well rise again this year. . . . The oil bulls of Houston have yet to prove that they can pump oil and create value at the same time."[1011]

- March 21, 2017 – An MIT study questioned the U.S. Energy Information Administration's rosy projections on the abundance and availability of shale gas and oil. Analyzing field data on oil wells in North Dakota's Williston Basin, the authors found that advances in fracking technology, such as the shift to longer laterals per well, have had a more modest impact on boosting oil and gas production than the agency had estimated. At the same time, the attraction of operators to the most productive areas of basins has had a greater impact. As time goes by, the prime drilling spots with the easy-to-extract oil or gas will get used up, the authors argued, and technology may not be able to compensate.[1012, 1013]

- July 7, 2016 – "Oil-field-services companies are depleted after slashing prices and laying off workers, and their slow recovery could crimp the energy industry's overall ability to bounce back from the oil bust," according to the *Wall Street Journal*. Almost 70 percent of fracking equipment in the United States has been idled, and 60 percent of field workers involved in fracking have been laid off. Halliburton alone has laid off over 28,500

[1010] Carlson, C. (2017, June 16). Pennsylvania gas drilling fee revenue falls for third year. *WENY.com.* Retrieved from http://www.weny.com/story/35680098/pennsylvania-gas-drilling-fee-revenue-falls-for-third-year?utm_medium=social&utm_source=twitter_WENYTV

[1011] America's shale firms don't give a frack about financial returns. (2017, March 25). *Economist.* Retrieved from https://www.economist.com/news/business-and-finance/21719436-exploration-and-production-companies-are-poised-go-another-investment-spree-americas

[1012] Montgomery, J. B., & O'Sullivan, F. M. (2017). Spatial variability of tight oil well productivity and the impact of technology. *Applied Energy, 195,* 344–355. doi: 10.1016/j.apenergy.2017.03.038

[1013] Marshall, C. (2017, October 6). Studies attack conventional wisdom on natural gas. *E&E News.* Retrieved from https://www.eenews.net/stories/1060062933 workers, which is one third of its workforce. More than 70 oilfield services companies have filed for bankruptcy since the beginning of 2015.[1014]

- June 15, 2016 – Billions of dollars of proven reserves have become unproven this year, as "59 U.S. oil and gas companies deleted the equivalent of 9.2 billion barrels, more than 20 percent of their inventories," according to *Bloomberg*. In 2009, the Securities and Exchange Commission (SEC) made it easier for the companies to include in their proven reserves undeveloped acreage and wells that wouldn't be drilled for years on the grounds that "shale prospects are predictable across wide expanses." Since then, the SEC has become more strict about inflated reserves estimates.[1015]

- May 16, 2016 – *CNN Money* reported on the two latest U.S. oil and gas bankruptcies: SandRidge Energy's Chapter 11 filing was based on roughly $4 billion of debt and came the week after the biggest such bankruptcy to date—that of Linn Energy with more than $10 billion in debt. There had been at least 29 U.S. oil and gas bankruptcies in 2016 at the date of the article's publication, bringing the 2015-2016 total to at least 64. "The industry has historically been full of wildcatters and speculators. It's not surprising we're going through this boom-and-bust cycle," the article quoted the managing director at oil restructuring firm SOLIC Capital, George Koutsonicolis, as saying.[1016]

- May 9, 2016 – "The pace of oil patch bankruptcies is picking up," a *Forbes* piece read, listing the 15 biggest such bankruptcies to date. "All told, 69 oil and gas producers with $34.3 billion in cumulative secured and unsecured debt have gone under."[1017]

- March 25, 2016 – Oil and gas borrowers "feasted on what Bloomberg estimates was $237 billion of easy money without scrutinizing whether the loans could endure a drastic downturn," according to a *Washington Post* piece focusing on one company, Swift Energy, which itself was $1.349 billion in debt and had entered bankruptcy. Despite having been cautious prior to the Texas fracking boom, "[a]s the company began to frack more often, the amount it spent on exploration and drilling skyrocketed by hundreds of millions of dollars." Those expenses combined with global developments led to its failure, along with over 40 other oil and gas companies in 2015. "The consequences are far-reaching. The U.S. oil industry, having grown into a giant on par with Saudi Arabia's, is shrinking, with the biggest collapse in investment in energy in 25 years. More than 140,000 have lost energy jobs. Banks are bracing for tens of billions of dollars of

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[1014] Sider, A. (2016, July 7). Revving up oil fields won't be so easily done. *Wall Street Journal.* Retrieved from http://www.wsj.com/articles/revving-up-oil-fields-wont-be-so-easily-done-1467883807
[1015] Loder, A. (2016, June 15). Why billions in proven shale oil reserves suddenly became unproven. *Bloomberg.* Retrieved from http://www.bloomberg.com/news/articles/2016-06-15/shale-drillers-paper-wells-draw-sec-scrutiny-before-vanishing
[1016] Egan, M. (2016, May 16). Oil bankruptcies mount despite crude rebound. *CNN Money.* Retrieved from http://money.cnn.com/2016/05/16/investing/sandridge-energy-oil-bankruptcy/
[1017] Helman, C. (2016, May 9). The 15 biggest oil bankruptcies (so far). *Forbes.* Retrieved from http://www.forbes.com/sites/christopherhelman/2016/05/09/the-15-biggest-oil-bankruptcies-so-far/#7c765e10739b

defaults, and economists and lawyers predict the financial wreckage will accelerate this year."[1018]

- March 10, 2016 – Crude oil production is not falling as quickly as predicted, given the sharp decline in prices and the drop-off in new drilling and fracking operations. As reported by Reuters, this disconnect is due to refracking of older wells, along with other unconventional techniques such as "choking" and "lifting," which can extend the productive lives of wells or otherwise capture more product from them.[1019]

- March 1, 2016 – An analysis of fracking trends in the journal *Nature* concluded that a European shale gas boom was unlikely due to disappointing early yields (Poland, Lithuania and Denmark), links to earthquakes (United Kingdom), and intense public opposition in densely populated areas throughout the continent.[1020]

- June 19, 2015 – A *Bloomberg Business* analysis of the 62 drilling companies in the Bloomberg Intelligence North America Independent Exploration and Production Index found that the companies' debt continued to be a major problem. For 27 of the 62 companies, interest payments were consuming more than 10 percent of revenue. Drillers' debt rose to $235 billion at the end of the first quarter, a 16 percent increase over the year prior. *Bloomberg Business* expressed concern that shale drillers have "consistently spent money faster than they've made it, even when oil was $100 a barrel." S&P assigned speculative, or junk, ratings to 45 of the 62 companies in Bloomberg's index.[1021]

- April 7, 2015 – A Moody's Investors Service analysis of LNG prospects found that lower oil prices were causing suppliers to defer or cancel most proposed LNG projects. Moody's found that this was due in part to the drop in international oil prices relative to U.S. natural gas prices, thus removing the economic advantage of U.S. LNG projects. Moody's stated, "LNG is a capital-intensive infrastructure business prone to periodic construction cycles that lead to overcapacity, which we expect will continue for the rest of the decade."[1022]

- March 20, 2015 – A study by the Energy Watch Group in Germany found that the costs of allowing fracking in Germany would outweigh the benefits, noting in part that natural gas trading in the United States has been declining since 2009. The study also noted the

[1018] Harlan, C. (2016, March 25). The big bust in the oil fields. *The Washington Post.* Retrieved from https://www.washingtonpost.com/news/wonk/wp/2016/03/25/the-big-bust-in-the-oil-fields/
[1019] Gopinath, S., & Gayathri, A. (2016, March 10). Forget fracking. Choking and lifting are latest efforts to stem U.S. shale bust. *Reuters*. Retrieved from http://www.reuters.com/article/us-usa-shale-analysis-idUSKCN0WB1AI
[1020] Inman, M. (2016). Can fracking power Europe? *Nature*, *531*, 22-24. Retrieved from http://www.nature.com/news/can-fracking-power-europe-1.19464
[1021] Loder, A. (2015, June 18). The shale industry could be swallowed by its own debt. *Bloomberg Business*. Retrieved from http://www.bloomberg.com/news/articles/2015-06-18/next-threat-to-u-s-shale-rising-interest-payments
[1022] Moody's Investors Service. (2015, April 7). Lower oil prices cause suppliers of liquefied natural gas to nix projects. Retrieved from https://www.moodys.com/research/Moodys-Liquefied-natural-gas-projects-nixed-amid-lower-oil-prices--PR_322439

costs of infrastructure, environmental and health risks and pointed to the need to expand renewable energy.[1023]

- December 19, 2014 – An International Energy Agency (IEA) report projected that U.S. domestic oil supplies, dominated by fracking, face challenges, and oil output from shale formations output, will level off and decline in the early 2020s.[1024] IEA Chief Economist Fatih Birol said, "A well-supplied oil market in the short-term should not disguise the challenges that lie ahead."[1025]

- August 29, 2014 – Andrew Nikiforuk, a Canadian energy analyst, reported on diminishing returns and the higher-cost, higher-risk nature of fossil fuel extraction by fracking. Nikiforuk wrote, "Most of the world's oil and gas firms are now pursuing extreme hydrocarbons because the cheap and easy stuff is gone…. That means industry will spend more good money chasing poor quality resources. They will inefficiently mine and frack ever larger land bases at higher environmental costs for lower energy returns."[1026]

- July 29, 2014 – According to the U.S. Energy Information Administration, energy companies are incurring increasing debt and selling assets to continue drilling in shale. "Based on data compiled from quarterly reports, for the year ending March 31, 2014, cash from operations for 127 major oil and natural gas companies totaled $568 billion, and major uses of cash totaled $677 billion, a difference of almost $110 billion. This shortfall was filled through a $106 billion net increase in debt and $73 billion from sales of assets . . ."[1027]

- July 2014 – Researchers at the Washington, DC-based Environmental Law Institute and Washington & Jefferson College in Pennsylvania collaborated to produce a report designed in part to help communities avoid the "boom and bust" cycles of extractive industries. Authors warned, "While resource extraction has long been regarded as an economic benefit, a body of academic literature suggests that long term growth based chiefly on resource extraction is rare." Confounding factors include transience of the workforce, localized inflation, widening disparities in royalties and impact fee

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[1023] Sagener, N. (2015, March 26). Fracking costs outweigh benefits for Germany and Europe, study says. *EurActiv*. Retrieved from http://www.euractiv.com/sections/energy/fracking-costs-outweigh-benefits-germany-and-europe-study-says-313087
[1024] International Energy Agency. (2014, December). World Energy Outlook 2014 Executive Summary. Retrieved from http://www.iea.org/publications/freepublications/publication/WEO_2014_ES_English_WEB.pdf
[1025] Dimick, D. (2014, December 19). How long can the U.S. oil boom last? *National Geographic*. Retrieved from http://news.nationalgeographic.com/news/2014/12/141219-fracking-oil-supply-price-reserves-profits-environment/
[1026] Nikiforuk, A. (2014, August 29). A big summer story you missed: Soaring oil debt returns diminish as energy companies resort to higher-cost, higher-risk hydrocarbons. *The Tyee.* Retrieved from http://thetyee.ca/Opinion/2014/08/29/Soaring-Oil-Debt-Summer/
[1027] US Energy Information Administration. (2014, July 29). As cash flows flatten, major energy companies increase debt, sell assets. *Today in Energy*. Retrieved from http://www.eia.gov/todayinenergy/detail.cfm?id=17311

disbursement, commodity price volatility, and communities overspending on infrastructure.[1028]

- June 19, 2014 – Energy analyst Deborah Lawrence Rogers outlined the spiraling debt and severe deterioration of the assets of five major shale gas drillers over the last five years. She concluded, "This is not sustainable. It could be argued that it is not even moral. It is a failed business model of epic proportion. While companies could make the argument at one time that this was a short term downtrend, that no longer holds water because this pattern is long term."[1029]

- April 10, 2014 – A report by a petroleum geologist and petroleum engineer concluded the 100-year supply of shale gas is a myth, distinguished between what is technically recoverable and economically recoverable shale gas, and asserted that at current prices, New York State has no economically recoverable shale gas.[1030]

- February 28, 2014 – Maria van der Hoeven, Executive Director of the IEA, said in an interview with *The Christian Science Monitor* that there is only a decade left in the U.S. shale oil and gas boom, noting that her agency's analysis predicts that production will soon flatten out and, by 2025, begin to decline.[1031]

- December 18, 2013 – A University of Texas study in *Proceedings of the National Academy of Sciences* found that fracking well production drops sharply with time, which undercuts the oil and gas industry's economic projections.[1032] In an interview about the study with *StateImpact NPR* in Texas, Tad Patzek, Chair of the Department of Petroleum and Geosystems Engineering at University of Texas at Austin, noted that fracking "also interferes now more and more with daily lives of people. Drilling is coming to your neighborhood, and most people abhor the thought of having somebody drilling a well in their neighborhood."[1033]

[1028] Environmental Law Institute and Washington & Jefferson College. (2014, July). Getting the boom without the bust: Guiding Southwestern Pennsylvania through shale gas development. Retrieved from http://www.eli.org/sites/default/files/eli-pubs/getting-boom-final-paper-exec-summary-2014-07-28.pdf

[1029] Rogers, D. L. (2014, June 19). Huge CAPEX = free cash flow? Not in shales. *Energy Policy Forum.* Retrieved from http://energypolicyforum.org/2013/06/19/huge-capex-free-cash-flow-not-in-shales/

[1030] Labyrinth Consulting Services, Inc., Berman, A., and Pittinger, L. (2014). Resource Assessment of Potentially Producible Natural Gas Volumes From the Marcellus Shale, State of New York. Retrieved from: http://www.lwvny.org/

[1031] Unger, D. J. (2014, February 28). IEA chief: Only a decade left in US shale oil boom. *Christian Science Monitor*. Retrieved from http://www.csmonitor.com/Environment/Energy-Voices/2014/0228/IEA-chief-Only-a-decade-left-in-US-shale-oil-boom

[1032] Patzek, T. W., Male, F., & Marder, M. (2013). Gas production in the Barnett Shale obeys a simple scaling theory. *Proceedings of the National Academy of Sciences*, *110*(49), 19731-19736. doi: 10.1073/pnas.1313380110

[1033] Buchele, M. (2013, December 18). New study shows how gas production from "fracked" wells slows over time. *StateImpact*. Retrieved from http://stateimpact.npr.org/texas/2013/12/18/new-study-shows-how-gas-production-from-fracked-wells-slows-over-time/

- August 18, 2013 – *Bloomberg News* reported that low gas prices and disappointing wells have led major companies to devalue oil and gas shale assets by billions of dollars.[1034]

- October 21, 2012 – The *New York Times* reported that many gas drilling companies overproduced natural gas backed by creative financing and now "are committed to spending far more to produce gas than they can earn selling it." "We are all losing our shirts today," said Exxon CEO Rex Tillerson in the summer of 2012.[1035]

- July 13, 2012 – *The Wall Street Journal* reported that ITG Investment Research, at the request of institutional investors, evaluated the reserves of Chesapeake Energy Corporation's shale gas reserves in the Barnett and Haynesville formations and found them to be only 70 percent of estimates by Chesapeake's engineering consultant for the company's 2011 annual report. Chesapeake and its consultant defended their figures.[1036]

- August 23, 2011 – The U.S. Geological Survey (USGS) cut the government's estimates of natural gas in the Marcellus Shale from 410 trillion cubic feet to 84 trillion cubic feet, equivalent to a reduction from approximately 16 years of U.S. consumption at current levels of natural gas use, to approximately 3.3 years of consumption. The USGS's updated estimate was for natural gas that is technically recoverable, irrespective of economic considerations such as the price of natural gas or the cost of extracting it.[1037]

- June 26-27, 2011 – As reported in two *New York Times* stories, hundreds of emails, internal documents, and analyses of data from thousands of wells from drilling industry employees, combined with documents from federal energy officials, raised concerns that shale gas companies were overstating the amount of gas in their reserves and the profitability of their operations.[1038, 1039, 1040] The *New York Times*' public editor criticized the stories, but offered no evidence that the major findings were wrong.[1041] The *New York*

[1034] Monks, M., Penty, R., & De Vynck, G. (2013, August 18). Shale grab in U.S. stalls as falling values repel buyers. *Bloomberg*. Retrieved from http://www.bloomberg.com/news/2013-08-18/shale-grab-in-u-s-stalls-as-falling-values-repel-buyers.html
[1035] Krauss, C., & Lipton, E. (2012, October 20). After the boom in natural gas. *The New York Times*. Retrieved from http://www.nytimes.com/2012/10/21/business/energy-environment/in-a-natural-gas-glut-big-winners-and-losers.html?pagewanted=all
[1036] Wirz, M. (2013, July 13). Chesapeake reserve doubted. *Wall Street Journal*. Retrieved from http://online.wsj.com/news/articles/SB10001424052702303644004577523411723501548
[1037] United States Geological Survey. (2011, August 23). USGS releases new assessment of gas resources in the Marcellus shale, Appalachian Basin. *USGS Newsroom*. Retrieved from http://www.usgs.gov/newsroom/article.asp?ID=2893&from=rss_home#.Uok0mGRO_GA.
[1038] Urbina, I. (2011, June 25). Insiders sound an alarm amid a natural gas rush. *The New York Times*. Retrieved from http://www.nytimes.com/2011/06/26/us/26gas.html?pagewanted=all
[1039] U.S. Energy Information Administration. (2014, May 30). U.S. Natural Gas Summary. Retrieved from http://www.eia.gov/dnav/ng/ng_sum_lsum_dcu_nus_a.htm
[1040] Urbina, I. (2011, August 24). Geologists sharply cut estimate of shale gas. *The New York Times*. Retrieved from http://www.nytimes.com/2011/08/25/us/25gas.html
[1041] Brisbane, A. S. (2011, July 16). Clashing views on the future of natural gas. *The New York Times*. Retrieved from http://www.nytimes.com/2011/07/17/opinion/sunday/17pubed.html?gwh=7D408242717755A0E06B0D265498E177&gwt=pay&assetType=opinion&_r=0

Times' news editors publicly defended both stories against the public editor's criticism.[1042, 1043]

Disclosure of serious risks to investors

A snapshot of the dangers posed by natural gas drilling and fracking can be found in the annual Forms 10-K that oil and natural gas companies are required to file with the U.S. Securities and Exchange Commission (SEC). The information so contained in these reports, which provide a comprehensive summary of a company's financial performance, provides a window into the harms and risks of fracking that are otherwise shielded from view by "gag order" clauses in court settlements, non-disclosure agreements between industry and landowners, and trade secret claims in regards to the chemical ingredients of fracking fluid. In this way, the Form 10-K can serve as an imperfect surrogate for right-to-know data. Recently, Forms 10-K have been used to warn investors about risks from climate change lawsuits.

Federal law requires that companies offering stock to the public disclose in their Form 10-K, among other things, the "most significant factors that make the offering speculative or risky."[1044] In a review of Forms 10-K spanning the past decade available on the SEC's website, oil and natural gas companies have routinely warned of drilling's serious risks. In the words of Exxon Mobil Corporation's subsidiary XTO Energy, "our operations are subject to hazards and risks inherent in drilling."[1045] In the language of Range Resources Corporation: "development and exploratory drilling and production activities are subject to many risks."[1046]

Such hazards and risks include leaks, spills, explosions, blowouts, environmental damage, property damage, injury, and death. Chesapeake Energy Corporation has stated that "horizontal and deep drilling activities involve greater risk of mechanical problems than vertical and shallow drilling operations."[1047] Over the past 15 years, companies have combined horizontal drilling with hydraulic fracturing to tap natural gas and oil in shale formations.

The companies also routinely warn of inadequate insurance to cover drilling harms. According to XTO Energy, "we are not fully insured against all environmental risks, and

[1042] Brisbane, A. S. (2011, July 17). Times editors respond to my shale gas column. *The New York Times*. Retrieved from http://publiceditor.blogs.nytimes.com/2011/07/17/times-editors-respond-to-my-shale-gas-column/
[1043] Brisbane, A. S. (2011, July 30). Times editors respond to column on redactions. *The New York Times*. Retrieved from http://publiceditor.blogs.nytimes.com/2011/07/30/times-editors-respond-to-column-on-redactions/
[1044] See 17 C.F.R. § 229.503(c) (companies must disclose the "most significant" risks); 17 C.F.R. § 230.405 ("the term material, when used to qualify a requirement for the furnishing of information as to any subject, limits the information required to those matters to which there is a substantial likelihood that a reasonable investor would attach importance in determining whether to purchase the security registered"); 17 C.F.R. § 240.10b-5 (it is illegal "to make any untrue statement of a material fact or to omit to state a material fact . . . in connection with the purchase or sale of any security); 17 C.F.R. 249.310 (requiring Form 10-K, "for annual and transition reports pursuant to sections 13 or 15(d) of the Securities Exchange Act of 1934.")
[1045] XTO Energy Corp., Annual Report (Form 10-K) (Feb. 25, 2010) at 25.
[1046] Range Resources Corp., Annual Report (Form 10-K) (Feb. 24, 2015) at 22.
[1047] Chesapeake Energy Corp., Annual Report (Form 10-K) (Feb. 27, 2015) at 18.

no coverage is maintained with respect to any penalty or fine required to be paid by us."[1048] Range Resources states, "we can provide no assurance that our coverage will adequately protect us against liability from all potential consequences, damages and losses."[1049]

Houston-based Noble Energy provides a representative example of the risks that at least several drilling companies include in their annual reports. Noble states:

> Our operations are subject to hazards and risks inherent in the drilling, production and transportation of crude oil, natural gas and NGLs [natural gas liquids], including:
> - injuries and/or deaths of employees, supplier personnel, or other individuals;
> - pipeline ruptures and spills;
> - fires, explosions, blowouts and well cratering;
> - equipment malfunctions and/or mechanical failure on high-volume, high-impact wells;
> - leaks or spills occurring during the transfer of hydrocarbons from an FPSO [floating production storage and offloading vessels] to an oil tanker;
> - loss of product occurring as a result of transfer to a rail car or train derailments;
> - formations with abnormal pressures and basin subsidence which could result in leakage or loss of access to hydrocarbons;
> - release of pollutants;
> - surface spillage of, or contamination of groundwater by, fluids used in operations;
> - security breaches, cyber attacks, piracy, or terroristic acts;
> - theft or vandalism of oilfield equipment and supplies, especially in areas of active onshore operations;
> - hurricanes, cyclones, windstorms, or "superstorms," which could affect our operations in areas such as the Gulf Coast, deepwater Gulf of Mexico, Marcellus Shale or Eastern Mediterranean;
> - winter storms and snow which could affect our operations in the DJ Basin [Denver-Julesburg Basin in Colorado] or Marcellus Shale;
> - extremely high temperatures, which could affect third party gathering and processing facilities in the DJ Basin;
> - volcanoes which could affect our operations offshore Equatorial Guinea;
> - flooding which could affect our operations in low-lying areas;
> - harsh weather and rough seas offshore the Falkland Islands, which could limit certain exploration activities; and
> - pandemics and epidemics, such as the Ebola virus, which is ongoing in certain regions of West Africa and may adversely affect our business operations through travel or other restrictions.
>
> Any of these can result in loss of hydrocarbons, environmental pollution and other damage to our properties or the properties of others.[1050]

[1048] XTO Energy Corp., Annual Report (Form 10-K) (Feb. 25, 2010) at 17.
[1049] Range Resources Corp., Annual Report (Form 10-K) (Feb. 24, 2015) at 26.
[1050] Noble Energy, Annual Report (Form 10-K) (Feb. 19, 2015) at 38.

Noble has language similar to that found in other companies' annual reports about inadequate insurance and adds, "we do not have insurance for gradual pollution nor do we have coverage for penalties or fines that may be assessed by a governmental authority."[1051]

Forms 10-K are also a tool of disclosure for risks concerning climate change beyond specific negative impacts on operations (hurricanes, flooding, etc.) listed, for example, in Noble Energy's annual report cited above. In 2016, Chevron became the first major oil company to warn investors in its Form 10-K about the risk of climate change lawsuits: "Increasing attention to climate change risks has resulted in an increased possibility of governmental investigations and, potentially, private litigation against the company."[1052] Also in 2016, the SEC began investigating Exxon Mobil for valuing its assets in ways that do not account for the possible depreciation of oil and gas under a policy framework that shifts investments in energy away from fossil fuels and toward renewable sources.[1053] Under pressure from investors, Exxon agreed in December 2017 to disclose more details about climate risks by filing with the SEC, in a Form 8-K, a statement that said the company would no longer resist motions from shareholders seeking this information.[1054]

At this writing, it is not clear whether, under the current Administration, the SEC will continue its push toward investor disclosure of climate change risks.[1055] Nevertheless, the unsolved problem of methane leaks is increasingly recognized as a rising risk for oil and gas investors concerned that methane emissions are not transparently managed, may negate the claim that natural gas is more climate-friendly than coal, and hence pose a risk to their investments.[1056, 1057]

The risks identified by these oil and gas companies are not just hypothetical. Many, if not all of these risks are reflected in the evidence compiled in other sections of this Compendium.

1051 Noble Energy. Annual Report (Form 10-K) (Feb 19, 2015) at 79.

1052 Romm, J. (2017, March 2). Chevron is first oil major to warn investors of risks from climate change lawsuits. *ThinkProgress.* Retrieved from https://thinkprogress.org/chevron-admits-climate-lawsuits-threaten-profits-33937dd562fd/#.56j1qq4h3

1053 Olson, B., & Viswanatha, A. (2016, September 20). SEC probes Exxon over accounting for climate change. *Wall Street Journal*. Retrieved from https://www.wsj.com/articles/sec-investigating-exxon-on-valuing-of-assets-accounting-practices-1474393593

1054 Cushman, Jr., J. H., & Hasemyer, D. (2017, December 12). Exxon agrees to disclosure climate risks under pressure from investors. *InsideClimate News*. Retrieved from https://insideclimatenews.org/news/12122017/exxon-climate-risk-disclosure-sec-shareholder-investigation-pressure

1055 Griffen, P., & Jaffe, A. M. (2017, February 15). Are fossil fuel companies telling investors enough about the risks of climate change? *The Conversation.* Retrieved from https://theconversation.com/are-fossil-fuel-companies-telling-investors-enough-about-the-risks-of-climate-change-72562

1056 Connan, M.-S. (2016, December 1). *Methane: The next frontier for fossil fuel emissions.* Retrieved from https://us.allianzgi.com/en-us/insights/capital-markets-and-economics/methane-the-next-frontier-for-fossil-fuel-emissions

1057 Gilblom, K. (2017, December 19). Insidious gas leaks are casting doubts over Shell's clean credentials. *Bloomberg.* Retrieved from https://www.bloomberg.com/news/articles/2017-12-20/as-shell-gambles-on-gas-leaks-cast-cloud-over-clean-credentials

Medical and scientific calls for more study, reviews confirming evidence for harm, and calls for increased transparency and science-based policy

With increasing urgency, groups of medical and other health professionals and scientists are issuing calls for comprehensive, long-term study of the full range of potential health and ecosystem effects of drilling and fracking. These appeals underscore the accumulating evidence of harm, point to the major knowledge gaps that remain, and decry the atmosphere of secrecy and intimidation that continues to impede the progress of scientific inquiry. Published reviews and international governmental reports underscore the existing evidence of health risks including developmental, neurological, carcinogenic, respiratory, reproductive, and psychological. Health professionals and scientists in the United States and around the world increasingly call for the suspension of unconventional gas and oil extraction activities in order to limit, mitigate, or eliminate its serious, adverse public health hazards, including health threats from climate change.

- December 12, 2017 – Commissioned by the Australian government, the Scientific Inquiry into Hydraulic Fracturing in the Northern Territory released its Draft Final Report. Tasked with identifying and assessing the risks of shale gas fracking for Australia's remote Northern Territory—and with making recommendations to mitigate those risks where possible—the Inquiry describes a multiplicity of risks, including many that are ill-defined and understudied[1058] Most notably, it recommends a halt on all fracking production licenses until a two-to-three-year study can be launched to further understand the nature of the risks for the particular ecology and culture of the region."[1059] Fracking is currently prohibited in the Northern Territory, which is estimated to hold over one-third of Australia's shale gas.

- November 7, 2017 – In a commentary published in *JAMA*, two South Dakota physicians reviewed the data on the potential public health implications of fracking, including asthma, water contamination, exposures to fracking fluid, and exposure of workers to silica dust. They voiced specific concerns about parkinsonism, neuropathy, and kidney disease, and called for prospective toxicity studies.[1060]

- October 25, 2017 – Scientists and physicians (including two co-authors of this *Compendium*) reviewed the body of evidence on the potential of unconventional oil and natural gas (UOG) development and operations to contribute to neurological and developmental harm via increased air and water pollution in the surrounding communities where it takes place. Highlighting data gaps and research limitations (such

[1058] Scientific Inquiry into Hydraulic Fracturing in the Northern Territory. (2017). *Draft final report of the Scientific Inquiry into Hydraulic Fracturing in the Northern Territory.* Retrieved from https://frackinginquiry.nt.gov.au/inquiry-reports/draft-final-report
[1059] Reuters staff. (2017, December 12). Study seen needed before lifting fracking ban in remote Australia. *Reuters.* Retrieve from https://www.reuters.com/article/us-australia-fracking/study-seen-needed-before-lifting-fracking-ban-in-remote-australia-idUSKBN1E60TL
[1060] Wilke, R. A., & Freeman, J. W. (2017). Potential health implications related to fracking. *JAMA, 318*(17), 1645-1646. doi: 10.1001/jama.2017.14239

as the nondisclosure by industry of chemical mixtures), they nevertheless pinpointed evidence in the existing literature showing that "the chemicals that are used in or are byproducts of UOG operations have been linked to serious neurodevelopmental health problems in infants."[1061] Interviewed by the *Guardian*, a co-author said, "Given the profound sensitivity of the developing brain and the central nervous system, it is very reasonable to conclude that young children who experience frequent exposure to these pollutants are at particularly high risk for chronic neurological problems and disease."[1062] The research team concluded that there is "a need for public health prevention techniques, well-designed studies, and stronger state and national regulatory standards."

- October 23, 2017 – A Yale University research team reported that carcinogens involved in fracking operations have the potential to contaminate both air and water in nearby communities in ways that may increase the risk of childhood leukemia. The team identified 55 known or possible carcinogens that may be released into air and water from fracking operations. Of these, 20 are linked to leukemia or lymphoma.[1063] "This analysis creates a priority list of carcinogens to target for future exposure and health studies."[1064]

- July 31, 2017 – A review by a team of medical, psychological, occupational, and environmental health professionals concluded, "there appears to be an array of levels of psychosocial functioning that are deleteriously affected by the fracking process and industries and their aftermath." Though much of the research they identified linking fracking to psychological functioning was preliminary, documented impacts included: individual-level impacts, such as feelings of stress and powerlessness; community-level impacts, such as disrupted social fabric and new gender/sex imbalances in the community; collective trauma such as caused by a boom-and-bust cycle; and worker impacts, such as psychosocial impacts of being a transient worker. The review provided "an important first step in understanding the psychological toll that this energy development strategy has on fracking communities and sets the stage for advancements in research, clinical and policy, that will help us to better understand, assist, and advocate for those affected by fracking."[1065]

[1061] Webb, E., Moon, J., Dyrszka, L., Rodriguez, B., Cox, C., Patisaul, H., … London, E. (2017). Neurodevelopmental and neurological effects of chemicals associated with unconventional oil and natural gas operations and their potential effects on infants and children. *Reviews on Environmental Health.* Advance online publication. doi: 10.1515/reveh-2017-0008

[1062] Davis, N. (2017, October 25). Pollutants from fracking could pose health risk to children, warn researchers. *Guardian.* Retrieved from https://www.theguardian.com/environment/2017/oct/25/pollutants-from-fracking-could-pose-health-risk-to-children-warn-researchers

[1063] Elliot, E. G., Trihn, P., Ma, X., Leaderer, B. P., Ward, M. H., & Deziel, N. C. (2017). Unconventional oil and gas development and risk of childhood leukemia. *Science of the Total Environment, 576*. doi: 10.1016/j.scitotenv.2016.10.072

[1064] Yale News. (2016, October 24). Fracking linked to cancer-causing chemicals, new YSPH study finds. Retrieved from https://publichealth.yale.edu/news/article.aspx?id=13714

[1065] Hirsch, J. K., Smalley, K. B., Selby-Nelson, E. M., Hamel-Lambert, J. M., Rosmann, M. R., Barnes, T. A. Daniel, . . . LaFromboise, T. (2017). Psychosocial impact of fracking: A review of the literature on the mental health consequences of hydraulic fracturing. *International Journal of Mental Health and Addiction.* doi: 10.1007/s11469-017-9792-5

- May 1, 2017 – The Southwest Pennsylvania Environmental Health Project established a voluntary public health registry "aimed at tracking and eventually analyzing the impacts of shale gas development on people living near wells, impoundments, compressor stations and pipelines." According to a spokesperson, "The point is that the vast majority of independent science is looking at [shale gas development] and saying something's not good there. We need to know more… The findings of this registry will allow the health care community to be more informed about what problems people are experiencing when they walk into their offices. It will give the doctors some idea of what they should be looking for."[1066]

- February 8, 2017 – Addressing the community health and safety harms linked with camps that house temporary workers in extractive industries, the British Columbia Ministry of Aboriginal Relations and Reconciliation funded a research project carried out in consultation with Indigenous nations. The premise, that "Indigenous women and youth can experience negative impacts of resource extraction at every phase of resource development," was borne out by the project's community dialogues and literature review. "Increased domestic violence, sexual assault, substance abuse, and an increased incidence of sexually transmitted infections (STIs) and HIV/AIDS due to rape, prostitution, and sex trafficking are some of the recorded negative impacts of resource extraction projects, specifically as a result of the presence of industrial camps and transient work forces." The objectives of the project were to stimulate dialogue and to develop detailed protective steps for Nations, government, and industry in advance of the initiation of planned extraction projects in the region, such as the TransCanada and Spectra Energy pipelines, in order to prevent violence against women and other life changing negative effects linked to the industrial camps.[1067]

- February 8, 2017 – Los Angeles County health officials criticized as insufficient the allocation of only one million dollars by the Southern California Gas Company to fund an independent health study in the aftermath of the massive methane leak at Aliso Canyon that lasted from October 2015 until February 2016. "'It's a study, but not a health study,' said Angelo Bellomo, the Los Angeles County deputy director for health protection. 'It is not responsive to addressing the health needs and concerns to this community. More importantly, it's inconsistent with advice given to [South Coast Air Quality Management District] by health officials.'" Health experts from across the state had suggested a design "that was comprehensive and larger in scope as well as consistent with a state Senate bill introduced last year that estimated such a design would cost $13 million in the first three years, and up to $40 million to complete."[1068]

[1066] Hopey, D. (2017, May 1). Registry will study health impact from living near shale gas wells. *Pittsburgh Post-Gazette*. Retrieved from http://powersource.post-gazette.com/powersource/consumers-powersource/2017/05/01/Registry-will-study-health-impact-from-living-near-shale-gas-wells/stories/201705010018
[1067] Gibson, G., Yung, K., Chisholm, L., & Quinn, H., with Lake Babine Nation and Nak'azdli Whut'en. 2017. *Indigenous Communities and Industrial Camps: Promoting healthy communities in settings of industrial change.* Retrieved from http://www.thefirelightgroup.com/thoushallnotpass/wp-content/uploads/2016/03/Firelight-work-camps-Feb-8-2017_FINAL.pdf
[1068] Gazzar, B., & Abram, S. (2017, February 8). $1 million health study 'shortchanges' Porter Ranch gas leak victims, critics say. *Los Angeles Daily News*. Retrieved from https://www.dailynews.com/2017/02/08/1-million-health-study-shortchanges-porter-ranch-gas-leak-victims-critics-say/

- January 19, 2017 – An epidemiologist at Brown University reviewed studies to date on health outcomes in communities living close to unconventional natural gas development, and identified areas requiring further study. "Future epidemiologic studies should implement personal exposure assessments to examine associations between individual contaminants and relevant health outcomes, particularly to explain associations seen with respiratory and birth outcomes," the author concluded."[1069]

- November 1, 2016 – The government of Scotland released a health impact assessment that reconfirmed the evidence for potential contamination of air and water, threats to worker health from silica dust exposure, and risks to the health of nearby residents.[1070]

- October 23, 2016 – In a unanimous vote of the society's 300-member House of Delegates, the Pennsylvania Medical Society called for a moratorium on new shale gas drilling and fracking in Pennsylvania and an initiation of a health registry in communities with pre-existing operations.[1071, 1072]

- October 11, 2016 – A group of health care professionals in Massachusetts called for an immediate moratorium on major new natural gas infrastructure until the impact of these projects on the health of the communities affected can be adequately determined through a Comprehensive Health Impact Assessment.[1073] The group noted that the operation of natural gas facilities risks human exposures to toxic, cancer-causing, and radioactive pollution due to the presence of naturally co-occurring contaminants, toxic additives to the hydraulic fracturing process, and through the operation of transmission pipelines.[1074]

- September 15, 2016 – A systematic review of 45 studies, primarily but not exclusively addressing conventional oil and gas activities, showed an emerging body of evidence documenting harm to reproductive health from residential and occupational exposure to these operations. The strongest evidence existed for increased risk of miscarriage, prostate cancer, birth defects, and decreased semen quality. Authors state that there is "ample evidence for disruption of the estrogen, androgen, and progesterone receptors with individual chemicals and waste products related to oil and gas extraction," and "impacts from unconventional oil and gas activities will likely be greater, given that

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[1069] Stacy, S. L. (2017). A Review of the Human Health Impacts of Unconventional Natural Gas Development. *Current Epidemiology Reports, 4,* 38–45. doi: 10.1007/s40471-017-0097-9

[1070] Health Protection Scotland. (2016). *A health impact assessment of unconventional oil and gas in Scotland, Vol. 1.* Retrieved from http://www.hps.scot.nhs.uk/resourcedocument.aspx?resourceid=3102

[1071] Pennsylvania Medical Society (2016, October 23). Resolution 16-206: Pennsylvania Medical Society support for a moratorium on fracking. Retrieved from https://www.pamedsoc.org/PAMED_Downloads/HODAEC/16-206.pdf

[1072] Hopey, D. (2016, October 28). Doctors call for a state ban on drilling and fracking. *Pittsburgh Post-Gazette*. Retrieved from http://www.post-gazette.com/local/region/2016/10/27/Doctors-group-calls-for-moratorium-on-fracking-in-Pennsylvania/stories/201610270226

[1073] Massachusetts Health Care Professionals Against Fracked Gas (2016, October). Call for a moratorium on natural gas projects undergoing construction or review in the Commonwealth of Massachusetts. Retrieved from http://mhcpafg.org/

[1074] Massachusetts Health Care Professionals Against Fracked Gas. (2016, February 20). The role of comprehensive health impact assessment in evaluating natural gas infrastructure proposals in Massachusetts. Retrieved from http://mhcpafg.org/

unconventional activities have many similarities to conventional ones and employ dozens of endocrine-disrupting chemicals in the process of hydraulic fracturing."[1075]

- September 14, 2016 – In a commentary about fracking in the *American Journal of Public Health*, Weill Cornell Medicine physicians wrote, "mounting empirical evidence shows harm to the environment and to human health . . . and we have no idea what the long-term effects might be. . . . Ignoring the body of evidence, to us, is not a viable option anymore."[1076]

- July 7, 2016 –The UK health professional organization Medact released an updated assessment of the potential health impacts of shale fracking in England that confirm the findings of its 2015 report, *Health and Fracking*. The new report, *Shale Gas Production in England,* concluded, "Our view that the UK should abandon its policy to encourage [shale gas production] remains unchanged." The new report included hundreds of new academic papers addressing impacts on air and water quality, health, climate change, social wellbeing, economics, noise and light pollution, and seismic events. Still, authors wrote, "the absence of an independent social, health and economic impact assessment of [shale gas production] at scale is a glaring omission. Given the availability of alternative sources of energy, these are grounds for placing an indefinite moratorium on SGP (a position adopted by many jurisdictions across the world) until such time that there is greater clarity and certainty about the relative harms and benefits of shale gas."[1077]

- May 31, 2016 – "There are too many science, technology and risk-assessment gaps to green-light fracking in western Newfoundland," according to a panel that studied the question. In an interview with Canada's *Globe and Mail*, panel leader and engineering professor Ray Gosine said, "The science, the studies that have been done, have been somewhat limited – certainly limited compared to what we'd expect to have done in order to plan this kind of operation…. There are a number of gaps and deficiencies that are significant."[1078]

- May 13, 2016 – Physicians for Social Responsibility called for a ban on hydraulic fracturing, pointing both to the irremediable climate harm caused by methane emissions as well to the multiple health risks from industrial-scale water consumption, air pollution, seismic effects, the generation of large quantities of toxic liquid waste, and long-term impacts on drinking water aquifers. "We cannot stay healthy in an unhealthy environment. Nor can we survive indefinitely on a planet growing hotter and more prone to extreme, unpredictable and destructive weather. These factors impel PSR to call for a

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[1075] Balise, V. D., Meng, C-X., Cornelius-Green, J. N., Kassotis, C. D., Kennedy, R., & Nagel, S. C. (2016). Systematic review of the association between oil and natural gas extraction processes and human reproduction. *Fertility and Sterility, 106*(4). doi: 10.1016/j.fertnstert.2016.07.1099

[1076] Finkel, M. L., & Law, A. (2016). The rush to drill for natural gas: a five-year update. *American Journal of Public Health, 106*(10). doi: 10.2105/AJPH.2016.303398

[1077] McCoy, D. & Munro, A. (2016). *Shale gas production in England: An updated public health assessment.* Retrieved from http://www.medact.org/wp/wp-content/uploads/2016/07/medact_shale-gas_WEB.pdf

[1078] Bailey, S. (2016, May 31). Too many gaps to recommend fracking in Newfoundland: Panel. *Globe and Mail*. Retrieved from http://www.theglobeandmail.com/report-on-business/industry-news/energy-and-resources/too-many-unknowns-to-recommend-fracking-in-western-newfoundland-panel/article30216746/

ban on fracking and for a rapid transition to cleaner, healthier, carbon-free sources of energy."[1079]

- March 27, 2016 – Noting that many chemicals used in fracking fluids are known or suspected endocrine disruptors, a group of public health researchers called for an endocrine-centric component for health assessments in areas impacted by oil and gas operations. The team outlined a series of recommendations to assess the "potential endocrine-related risks from chemical exposures associated with oil and natural gas operations. We present these recommendations in light of the growing body of information regarding both chemical concentrations in the environment and adverse health outcomes reported in humans and wildlife."[1080]

- January 6, 2016 – A Yale University team of epidemiologists called for a systematic evaluation of chemicals in fracking fluid and wastewater for reproductive and development toxicity. While basic toxicity information is lacking for more than three-quarters of the more than 1,000 chemicals known to be used in fracking fluid, many of the remainder, the authors note, are linked to reproductive and developmental harm. "Therefore, carefully designed, rigorous exposure, and epidemiologic studies are urgently needed to investigate public health uncertainties…. The 67 chemicals we identified as possibly associated with either reproductive or developmental toxicity with a current or proposed federal drinking water standard or health-based guideline represent a feasible starting point for evaluation in future drinking water exposure studies or human health studies…."[1081]

- November 24, 2015 – A Harvard University team identified a trend toward increasing chemical secrecy and less transparency by examining 96,000 chemical disclosure forms filed by fracking companies between March 2011 and April 2015. These forms were submitted to the Fracfocus website, a chemical disclosure portal for the fracking industry that operates on a voluntary basis but for which reporting in mandated in more than 20 states. Fracfocus is the largest public database on chemicals used in U.S. fracking operations.[1082] Companies involved in fracking withheld chemical data at significantly higher rates in 2015 (16.5 percent) as compared to 2011-2013 (11 percent). The research team also found that withholding drops by a factor of four when companies report aggregate data without attribution to the specific products in the fracking fluid. The

[1079] Physicians for Social Responsibility (2016, May 13). PSR position statement calling for a ban on hydraulic fracturing. Retrieved from http://www.psr.org/assets/pdfs/psr-fracking-policy.pdf
[1080] Kassotis, C. D., Tillitt, D. E., Lin, C-H., Mcelroy, J. A., & Nagel, S. (2016). Endocrine-disrupting chemicals and oil and natural gas operations: Potential environmental contamination and recommendations to assess complex environmental mixtures. *Environmental Health Perspectives, 124*(3). doi: 10.1289/ehp.1409535
[1081] Elliot, E. G., Ettinger, A. S., Leaderer, B. P., Bracken, M. B., & Deziel, N. C. (2016). A systematic evaluation of chemicals in hydraulic-fracturing fluids and wastewater for reproductive and developmental toxicity. *Journal of Exposure Science and Environmental Epidemiology.* Advance online publication. doi: 10.1038/jes.2015.81
[1082] Song, L. (2015, Nov. 24). What chemicals are used in fracking? Industry discloses less and less. *InsideClimate News.* Retrieved from https://insideclimatenews.org/news/24112015/fracking-natural-gas-drilling-chemicals-frac-focus-study

authors called for state governments to retain authority in requiring disclosure of "product-specific ingredient lists."[1083]

- August 7, 2015 – While acknowledging the "dramatic increase in the number of peer-reviewed published studies" on environmental and health impacts of fracking, Weill Cornell Medical College's Dr. Madelon Finkel and co-author PSE Healthy Energy's Jake Hays called for more well-designed longer-term epidemiologic studies to quantify the connections between fracking-related risk factors and health outcomes. Without such studies it is challenging to capture, for example, outcomes such as cancer that take many years to present. The authors described several important studies that are currently underway that will add to the body of knowledge in the future.[1084]

- June 9, 2015 – Information on individual exposures and local environmental conditions prior to the commencement of fracking in a given area is often "unavailable or hard to obtain. These and other data gaps have hindered the kind of large-scale epidemiological studies that can link exposures to actual health outcomes, with valid comparison groups," wrote public health journalist David Tuller in the journal *Health Affairs*.[1085] In an interview with *Michigan Radio*, Tuller noted that, because well development happens quickly, there was generally a lack of pre-drilling baseline studies.[1086]

- April 17, 2015 – Using sophisticated Geographic Information Systems (GIS) tools to examine distribution of fracking wells compared to distribution of vulnerable populations, Clark University researchers found consistent evidence that, in the Pennsylvania Marcellus Shale region, census tracts with potential exposure to pollution from fracking wells contained "significantly higher" percentages of poor people. They also found clusters of vulnerable populations concentrated near drilling and fracking in all three states they studied: Pennsylvania (for poverty and elderly population), West Virginia (for poverty, elderly population, and education level) and Ohio (for children). Researchers also reported difficulty in accessing high quality and consistent unconventional well data in all three states, demonstrating an "urgent need" for common data collection and reporting.[1087] Another GIS-based study sought to begin to fill this gap in data on spatially distributed risks of fracking, identifying Pennsylvania populations at "very high" and "high" risk in over a dozen counties. The author called for more focus on those areas to understand the impacts of fracking.[1088]

[1083] Konschnik, K., & Dayalu, A. (2016). Hydraulic fracturing chemicals reporting: Analysis of available data and recommendations for policymakers. *Energy Policy, 88*. doi: 10.1016/j.enpol.2015.11.002

[1084] Finkel, M. L. & Hays, J. (2015). Environmental and health impacts of 'fracking': Why epidemiological studies are necessary. *Journal of Epidemiology and Community Health*. Advance online publication. doi: 10.1136/jech-2015-205487

[1085] Tuller, D. (2015). As fracking booms, dearth of health risk data remains. *Health Affairs*, *34* (6), 903-906.

[1086] Williams, R. (June 9, 2015). Why there are gaps in public health studies on fracking. *Michigan Radio.* Retrieved from http://michiganradio.org/post/why-there-are-gaps-public-health-studies-fracking#stream/0

[1087] Ogneva-Himmelberger, Y., & Huang, L. (2015). Spatial distribution of unconventional gas wells and human populations in the Marcellus Shale in the United States: Vulnerability analysis. *Applied Geography, 60*. 165-174.

[1088] Meng, Q. (2015). Spatial analysis of environment and population at risk of natural gas fracking in the state of Pennsylvania, USA. *Science of the Total Environment, 515-516.* 198-206.

- March 30, 2015 – The UK medical organization Medact published a report, *Health & Fracking: The Impacts and Opportunity Costs*, which concluded that fracking poses significant risks to public health and called for an immediate moratorium to allow time for a full and comprehensive health and environmental impact assessment to be completed.[1089] The report was supported by a letter published in the *British Medical Journal* calling for shale gas development to be put on hold, signed by the Climate and Health Council and over a dozen senior health professionals. The letter stated, "The arguments against fracking on public health and ecological grounds are overwhelming. There are clear grounds for adopting the precautionary principle and prohibiting fracking."[1090]

- February 17, 2015 – Writing in the *Canadian Medical Association Journal*, a public health scientist and medical doctor briefly reviewed the human health risks of fracking documented to date and made the case for a health care worker role in insisting on improved understanding. They cited worker and community safety issues as the biggest short-term risks, but emphasized that more needs to be known "before health care providers can definitively respond to their patients' and communities' concerns.… Physicians may wish to advocate delaying new development activities until the potential health effects are better understood."[1091]

- January 22, 2015 –The acting head of research at the Cancer Association of South Africa, Carl Albrecht, said that known carcinogenic chemicals used in fracking could lead to an epidemic of cancer in South Africa's Karoo desert. As South Africa was poised to publish draft regulations, Albrecht said that the effect of fracking on human health was ignored.[1092]

- January 19, 2015 – In an article that reviewed research and research gaps, a team of British and U.S. medical and scientific professionals urged the United Kingdom and other nations to engage in science before engaging in fracking. They warned that even strong regulations may not effectively address air pollution from fracking, and that "permanent, adverse environmental, climatic, and population health impacts" may exist in some cases.[1093]

- December 17, 2014 – In an editorial, Rutgers University environmental exposure expert Paul J. Lioy (now deceased) highlighted fracking as an area in which accurate exposure monitoring and risk assessment did not yet exist. Lioy emphasized that the relevant

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1089 Medact. (2015). *Health & fracking: The impacts and opportunity costs.* London: McCoy, D. & Saunders, P.
1090 Stott, R., Atkinson, S., Montgomery, H., Rao, M., McKee, M., Gerada, C., . . . Popay, J. (2014). Public Health England's draft report on shale gas extraction. *BMJ, 348.* Retrieved from http://www.bmj.com/content/348/bmj.g2728/rr
1091 Bharadwaj, L. & Goldstein, B. D. (2015). Shale gas development in Canada: What are the potential health effects? *CMAJ, 187*(3), E99-E100.
1092 Vecchiatto, P. (January 22, 2015). Chemicals used in fracking 'could cause cancer.' *Business Day BDlive.* Retrieved from http://www.bdlive.co.za/business/energy/2015/01/22/chemicals-used-in-fracking-could-cause-cancer
1093 Hays, J., Finkel, M. L., Depledge, M., Law, A., & Shonkoff, S. B. C. (2015). Considerations for the development of shale gas in the United Kingdom. *Science of the Total Environment, 512–513,* 36–42. doi: 10.1016/j.scitotenv.2015.01.004

research was compartmentalized and fragmented and that exposures and health outcomes around unconventional natural gas development need to be systematically addressed through "well-defined exposure studies in communities and workplaces."[1094]

- December 5, 2014 – A team of medical and scientific researchers, including from the Institute for Health and Environment at the State University of New York (SUNY) at Albany, reviewed the scientific evidence that both adult and early life—including prenatal—exposure to chemicals from fracking operations can result in adverse reproductive health and developmental effects. These include: endocrine-disrupting chemicals potentially increasing risk for reproductive problems, breast cancer, abnormal growth and developmental delays, and changes in immune function; benzene, toluene and xylene (BTX chemicals) increasing risk for impaired sperm quantity and quality in men and menstrual and fertility problems in women; and heavy metals increasing the risk of miscarriage and/or stillbirths. Potential exposures occur through both air and water. Based on their review, the authors concluded, "Taken together, there is an urgent need for the following: 1) biomonitoring of human, domestic and wild animals for these chemicals; and 2) systematic and comprehensive epidemiological studies to examine the potential for human harm."[1095] Lead author Susan Nagel said in an accompanying interview, "We desperately need biomonitoring data from these people. What are people actually exposed to? What are the blood levels of people living in these areas? What are the levels in the workers?"[1096]

- November 12, 2014 – A team of Australian researchers reviewed the strength of evidence for environmental health impacts of fracking based on publications from 1995 to 2014. They noted that the rapid expansion of fracking had outstripped the pace of science and that most studies focused on short-term, rather than long-term, health. Hence, "very few studies examined health outcomes with longer latencies such as cancer or developmental outcomes." Noting that no evidence exists to rule out health impacts, the team called for direct and clear public health assessments before projects are approved, longitudinal studies that include baseline data, and government and industry transparency.[1097]

- September 15, 2014 – Researchers led by University of Rochester's Environmental Health Sciences Center conducted interviews in New York, North Carolina, and Ohio to evaluate community health concerns about unconventional natural gas development. They identified many areas where more study is needed, including baseline measures of

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[1094] Lioy, P.J. (2015). Exposure science and its places in environmental health sciences and risk assessment: why is its application still an ongoing struggle in 2014? *Journal of Exposure Science and Environmental Epidemiology, 25*, 1-3. doi: 10.1038/jes.2014.59
[1095] Webb, E., Bushkin-Bedient, S., Cheng, A., Kassotis, C.D., Balise, V., & Nagel, S.C. (2014). Developmental and reproductive effects of chemicals associated with unconventional oil and natural gas operations. *Reviews on Environmental Health, 29*(4), 307-318. doi: 10.1515/reveh-2014-0057
[1096] Sample, I. (2014, December 5). Fracking chemicals could pose risks to reproductive health, say researchers. *Guardian.* Retrieved from http://www.theguardian.com/environment/2014/dec/05/fracking-chemicals-could-pose-risks-to-reproductive-health-say-researchers
[1097] Werner, A.K., Vink, S., Watt, K., & Jagals, P. (2015). Environmental health impacts of unconventional natural gas development: A review of the current strength of evidence. *Science of the Total Environment, 505*, 1127–1141. doi: 10.1016/j.scitotenv.2014.10.084

air quality, ongoing environmental monitoring, and health impact assessments. They noted that other areas where data are lacking involve the assessment of drilling and fracking impacts on vulnerable populations such as very young children, and the potential consequences of interactions between exposures resulting from shale gas extraction operations. Researchers suggested incorporating the input of potentially affected community members into the development of the research agenda.[1098]

- July 21, 2014 – An independent assessment report by Scientists for Global Responsibility and the Chartered Institute of Environmental Health reviewed current evidence across a number of issues associated with shale gas extraction by hydraulic fracturing, including environmental and public health risks, drawing on academic research. Among the report's conclusions: there are major shortcomings in regulatory oversight regarding local environmental and public health risks; there is a large potential for UK shale gas exploitation to undermine national and international efforts to tackle climate change; the water-intensive nature of the fracking process which could cause water shortages in many areas; the complete lack of evidence behind claims that shale gas exploitation will bring down UK energy bills; and concerns that it will impact negatively on UK energy security. Despite claims to the contrary, the report noted that evidence of local environmental contamination from shale gas exploitation is well reported in the scientific literature. It emphasizes that, "[t]here are widespread concerns over the lack of evidence on fracking-related health impacts," and that there is a lack of "substantive epidemiological study for populations exposed to shale gas extraction."[1099]

- July 18, 2014 – A working group of the Environmental Health Sciences Core Centers, supported by the National Institute of Environmental Health Sciences, reviewed the available literature on the potential health impacts of fracking for natural gas. They concluded that further research is urgently needed. Needs identified included: monitoring of air and water quality over the entire lifetime of wells; further epidemiologic research addressing health outcomes and water quality; and research addressing whether air pollution associated with fracking increases the risk of pulmonary and cardiovascular disease. The working group advocated for the participation of potentially affected communities in all areas of research.[1100]

- July 12, 2014 – Eli Avila, Pennsylvania's former Secretary of Health, said that health officials need to be proactive in protecting the public from the health effects of

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[1098] Korfmacher, K.S., Gray, K.M., & Haynes, E. (2014, September 15). Health impacts of unconventional natural gas development: A comparative assessment of community information needs in New York, North Carolina, and Ohio. *Project Report, UR-UNC-UC Supplement 2012-13.* Retrieved from http://www.urmc.rochester.edu/MediaLibraries/URMCMedia/environmental-health-sciences-center/COEC/documents/UNGD-information-needs-asssessment-Final-project-report-091514.pdf
[1099] Harrison, G., Parkinson, S., & McFarlane, G. (2014). Shale gas and fracking: examining the evidence. Published by Scientists for Global Responsibility (SGR) and the Chartered Institute of Environmental Health (CIEH). Retrieved from http://www.cieh.org/WorkArea/showcontent.aspx?id=53520
[1100] Penning, T. M., Breysse, P.N., Gray, K., Howarth, M., & Yan, B. (2014). Environmental health research recommendations from the Inter-Environmental Health Sciences Core Center Working Group on Unconventional Natural Gas Drilling Operations. *Environmental Health Perspectives, 122*(11), 1155-1159. doi: 10.1289/ehp.1408207

unconventional shale gas extraction. In 2011, funding was approved for a Pennsylvania public health registry to track drilling related complaints and address concerns, but was cut at the last minute. Speaking to the problem posed by the dearth of information, Avila asked, "How can you keep the public safe if you're not collecting data?"[1101]

- June 30, 2014 – The immediate past chair of the Executive Committee of the Council on Environmental Health for the American Academy of Pediatrics, Jerome A. Paulson, MD, called for industry disclosure of all ingredients of fracking fluid; thorough study of all air contaminants released from drilling and fracking operations and their protected dispersal patterns; and study and disclosure of fracking-related water contamination and its mechanisms. In a letter to the Pennsylvania Department of Environmental Protection (PA DEP), Paulson said:

> In summary, neither the industry, nor government agencies, nor other researchers have ever documented that [unconventional gas extraction] can be performed in a manner that minimizes risks to human health. There is now some evidence that these risks that many have been concerned about for a number of years are real risks. There is also much data to indicate that there are a number of toxic chemicals used or derived from the process, known or plausible routes of exposure of those chemicals to humans; and therefore, reason to place extreme limits on [unconventional gas extraction].[1102]

- June 20, 2014 – Highlighting preliminary studies in the United States that suggest an increased risk of adverse health problems among individuals living within ten miles of shale gas operations, a commentary in the British medical journal *The Lancet* called for a precautionary approach to gas drilling in the United Kingdom. According the commentary, "It may be irresponsible to consider any further fracking in the UK (exploratory or otherwise) until these prospective studies have been completed and the health impacts of fracking have been determined."[1103]

- June 20, 2014 – Led by an occupational and environmental medicine physician, a Pennsylvania-based medical and environmental science research team documented "… the substantial concern about adverse health effects of [unconventional natural gas development] among Pennsylvania Marcellus Shale residents, and that these concerns may not be adequately represented in medical records." The teams identified the continued need to pursue environmental, clinical, and epidemiological studies to better

[1101] *Associated Press*. (2014, July 12). Expert: Pa. didn't address fracking health impacts. *York Dispatch.* Retrieved from http://www.yorkdispatch.com/ci_26135724/expert-pa-didnt-address-fracking-health-impacts
[1102] Paulson, J.A. (2014, June 30). Letter to the Pennsylvania Department of Environmental Protection. Retrieved from http://concernedhealthny.org/letter-from-dr-jerome-a-paulson-to-the-pennsylvania-department-of-environmental-protection/
[1103] Hill, M. (2014, June 20). Shale gas regulation in the UK and health implications of fracking. *The Lancet*. Advance online publication. doi: 10.1016/S0140-6736(14)60888-6

understand associations between fracking, medical outcomes, and residents' ongoing concerns.[1104]

- June 17, 2014 – A discussion paper by the Nova Scotia Deputy Chief Medical Officer and a panel of experts identified potential economic benefits as well as public health concerns from unconventional oil and gas development. On the health impacts, they wrote, "uncertainties around long term environmental effects, particularly those related to climate change and its impact on the health of both current and future generations, are considerable and should inform government decision making." The report noted potential dangers including contamination of groundwater, air pollution, surface spills, increased truck traffic, noise pollution, occupational health hazards, and the generation of greenhouse gases. It also noted that proximity of potential fracking sites to human habitation should give regulators pause and called for a health impact assessment and study of long-term impacts.[1105] Responding to the report, the Environmental Health Association of Nova Scotia applauded the go-slow approach and called for a 10-year moratorium on fracking.[1106]

- May 29, 2014 – In New York State, more than 250 medical organizations and health professionals released a letter detailing emerging trends in the data on fracking that show significant risk to public health, air quality, and water, as well as other impacts. With signatories including the American Academy of Pediatrics, District II, the American Lung Association in New York, Physicians for Social Responsibility, and many leading researchers examining the impacts of fracking, they wrote, "The totality of the science — which now encompasses hundreds of peer-reviewed studies and hundreds of additional reports and case examples—shows that permitting fracking in New York would pose significant threats to the air, water, health and safety of New Yorkers."[1107, 1108]

- May 9, 2014 – In a peer-reviewed analysis, leading toxicologists outlined some of the potential harm and uncertainty relating to the toxicity of the chemical and physical agents associated with fracking, individually and in combination. While acknowledging the need for more research and greater involvement of toxicologists, they noted the potential for surface and groundwater contamination from fracking, growing concerns about air

[1104] Saberi, P., Propert, K. J., Powers, M. Emmett, E., & Green-McKenzie, J. (2014). Field survey of health perception and complaints of Pennsylvania residents in the Marcellus Shale region. *International Journal of Environmental Research and Public Health, 11*(6), 6517-6527. doi: 10.3390/ijerph110606517
[1105] Atherton, F. (2014, June 17). *Discussion paper: Hydraulic fracturing and public health in Nova Scotia.* Nova Scotia Hydraulic Fracturing Independent Review and Public Engagement Process.
[1106] Macdonald, M. (2014, June 17). Nova Scotia expert calls for go-slow approach for hydraulic fracturing. *The Canadian Press*. Retrieved from http://www.calgaryherald.com/health/Health+studies+needed+hydraulic+fracturing+approved+Nova+Scotia/9946368/story.html
[1107] Concerned Health Professionals of New York. (2014, May 29). Letter to Governor Cuomo and Acting Health Commissioner Howard A. Zucker. Retrieved from http://concernedhealthny.org/letters-to-governor-cuomo/
[1108] Hughes, K. (2014, May 29). NY fracking opponents call for moratorium of 3 to 5 years. *Daily Freeman*. Retrieved from http://www.dailyfreeman.com/general-news/20140529/ny-fracking-opponents-call-for-moratorium-of-3-to-5-years

pollution particularly in the aggregate, and occupational exposures that pose a series of potential hazards to worker health.[1109, 1110]

- May 1, 2014 – A 292-page report from a panel of top Canadian scientists urged caution on fracking, noting that it poses "the possibility of major adverse impacts on people and ecosystems" and that significantly more study is necessary to understand the full extent of the risks and impacts.[1111] The *Financial Post* reported that the panel of experts "found significant uncertainty on the risks to the environment and human health, which include possible contamination of ground water as well as exposure to poorly understood combinations of chemicals."[1112]

- April 30, 2014 – Medical professionals spoke out on the dearth of public health information collected and lack of long-term study five years into Pennsylvania's fracking boom. Walter Tsou, MD, MPH, past president of the American Public Health Association and former Health Commissioner of Philadelphia commented, "That kind of study from a rigorous scientific perspective has never been done." Other experts added, "There has been more health research involving fracking in recent years, but every study seems to consider a different aspect, and … there is no coordination."[1113]

- April 17, 2014 – In the preeminent *British Medical Journal,* authors of a commentary, including an endocrinologist and a professor of clinical public health, wrote, "Rigorous, quantitative epidemiological research is needed to assess the risks to public health, and data are just starting to emerge. As investigations of shale gas extraction in the US have continually suggested, assurances of safety are no proxy for adequate protection."[1114]

- April 15, 2014 – The *Canadian Medical Association Journal* reported on the increasing legitimacy of concerns about fracking on health: "While scientists and area residents have been sounding the alarm about the health impacts of shale gas drilling for years, recent

[1109] Society of Toxicology. (2014). Toxicologists outline key health and environmental concerns associated with hydraulic fracturing. *ScienceDaily*. Retrieved from http://www.sciencedaily.com/releases/2014/05/140509172545.htm

[1110] Goldstein, B. D., Brooks, B. W., Cohen, S. D., Gates, A. E., Honeycutt, M. E., Morris, J. B., . . . Snawder, J. (2014). The role of toxicological science in meeting the challenges and opportunities of hydraulic fracturing [Abstract]. *Toxicological Sciences, 139*(2). doi: 10.1093/toxsci/kfu061

[1111] The Expert Panel on Harnessing Science and Technology to Understand the Environmental Impacts of Shale Gas Extraction. (2014). Environmental impacts of Hurricane Mitch. *Council of Canadian Academies*. Retrieved from http://www.scienceadvice.ca/uploads/eng/assessments%20and%20publications%20and%20news%20releases/shale%20gas/shalegas_fullreporten.pdf

[1112] Canadian Press. (2014, May 1). Top Canadian scientists urge cautious approach to fracking until more known of impact. *Financial Post*. Retrieved from http://business.financialpost.com/2014/05/01/top-canadian-scientists-urge-cautious-approach-to-fracking-until-more-known-of-impact/?__lsa=3b44-76a1

[1113] Khan, N. (2014, April 30). Health impact of gas fracking left in the dark. *Pocono Record*. Retrieved from http://www.poconorecord.com/apps/pbcs.dll/article?AID=/20140430/NEWS90/404300301/-1/NEWS01

[1114] Law, A., Hays, J., Shonkoff, S. B., & Finkel, M. L. (2014). Public Health England's draft report on shale gas extraction [Abstract]. *BMJ, 1840*. doi: http://dx.doi.org/10.1136/bmj.g2728 studies, a legal decision and public health advocates are bringing greater legitimacy to concerns."[1115]

- March 3, 2014 – In the *Medical Journal of Australia*, researchers and a physician published a strongly worded statement, "Harms unknown: health uncertainties cast doubt on the role of unconventional gas in Australia's energy future." They cited knowledge to date on air, water, and soil pollution, and expressed concern about "environmental, social and psychological factors that have more indirect effects on health, and important social justice implications" yet to be understood. They wrote in summary:

  > The uncertainties surrounding the health implications of unconventional gas, when considered together with doubts surrounding its greenhouse gas profile and cost, weigh heavily against proceeding with proposed future developments. While the health effects associated with fracturing chemicals have attracted considerable public attention, risks posed by wastewater, community disruption and the interaction between exposures are of also of concern.[1116]

- March 1, 2014 – In the prestigious British medical journal *The Lancet*, researchers summarized workshops and research about the health impacts of fracking, noting that the scientific study on the health impacts of fracking is "in its infancy." Nevertheless, the existing evidence suggests, said these researchers, that health risks posed by fracking exceed those posed by conventional oil and gas wells due to the sheer number and density of well pads being developed, their proximity to densely populated areas, and the need to transport and store large volumes of materials.[1117]

- February 24, 2014 – In a review of the health effects of unconventional natural gas extraction published in the journal *Environmental Science & Technology*, leading researchers identified a range of impacts and exposure pathways that can be detrimental to human health. Noting how fracking disrupts communities, the review states, "For communities near development and production sites the major stressors are air pollutants, ground and surface water contamination, truck traffic and noise pollution, accidents and malfunctions, and psychosocial stress associated with community change." They concluded, "Overall, the current scientific literature suggests that there are both substantial public concerns and major uncertainties to address."[1118]

- August 30, 2013 – A summary of a 2012 workshop by the Institute of Medicine Roundtable on Environmental Health Sciences, Research, and Medicine featured various

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[1115] Glauser, W. (2014). New legitimacy to concerns about fracking and health. *Canadian Medical Association Journal, 186*(8), E245-E246. doi: 10.1503/cmaj.109-4725
[1116] Coram, A., Moss, J., & Blashki, G. (2014). Harms unknown: Health uncertainties cast doubt on the role of unconventional gas in Australia's energy future. *The Medical Journal of Australia, 200*(4), 210-213. doi: 10.5694/mja13.11023
[1117] Kovats, S., Depledge, M., Haines, A., Fleming, L. E., Wilkinson, P., Shonkoff, S. B., & Scovronick, N. (2014). The health implications of fracking. *The Lancet, 383*(9919), 757-758. doi: 10.1016/S0140-6736(13)62700-2
[1118] Adgate, J. L., Goldstein, B. D., & McKenzie, L. M. (2014). Potential public health hazards, exposures and health effects from unconventional natural gas development [Abstract]. *Environmental Science & Technology*. doi: 10.1021/es404621d

experts who discussed health and environmental concerns about fracking and the need for more research. The report in summary of the workshop stated, "The governmental public health system, which retains primary responsibility for health, was not an early participant in discussions about shale gas extraction; thus public health is lacking critical information about environmental health impacts of these technologies and is limited in its ability to address concerns raised by regulators at the federal and state levels, communities, and workers employed in the shale gas extraction industry."[1119]

- June 2013 – A group of three nursing professors published a cautionary review questioning the rollout of new shale-based energy practices at a time when, "anecdotal reports make clear that the removal of fossil fuels from the earth directly affects human health." Although the results of longterm studies are not yet available, the authors point to emerging evidence for negative human and ecologic health effects of fracking. Furthermore, they continue, "sufficient evidence has been presented to the [American Nurses Association], the American Public Health Association, and the American Medical Association's Resident and Fellow Section to result in a call for a moratorium on the issuance of new fracking permits nationally." They urge nurses to contribute to keeping health issues "front and center as we address national energy needs and policies."[1120]

- April 22, 2013 – In one of the first peer-reviewed nursing articles summarizing the known health and community risks of fracking, Professor Margaret Rafferty, Chair of the Department of Nursing at New York City College of Technology wrote, "Any initiation or further expansion of unconventional gas drilling must be preceded by a comprehensive Health Impact Assessment (HIA)."[1121]

- May 10, 2011 – In the *American Journal of Public Health*, two medical experts cautioned that fracking "poses a threat to the environment and to the public's health. There is evidence that many of the chemicals used in fracking can damage the lungs, liver, kidneys, blood, and brain." The authors urged that it would be prudent to invoke the precautionary principle in order to protect public health and the environment.[1122]

[1119] Coussens, C., & Martinez, R. (2013). *Health impact assessment of shale gas extraction: workshop summary*. Washington: The National Academies Press. Retrieved from http://www.iom.edu/Reports/2013/Health-Impact-Assessment-of-Shale-Gas-Extraction.aspx
[1120] McDermott-Levy, R., Kaktins, N., & Sattler, B. (2013). Fracking, the environment, and health: New energy practices may threaten public health. *American Journal of Nursing, 113*(6), 45-51.
[1121] Rafferty, M. A., & Limonik, E. (2013). Is shale gas drilling an energy solution or public health crisis? *Public Health Nursing, 30*(5), 454-462. doi: 10.1111/phn.12036
[1122] Finkel, M. L., & Law, A. (2011). The rush to drill for natural gas: A public health cautionary tale. *American Journal of Public Health, 101*(5), 784-785. doi: 0.2105/AJPH.2010.300089

Conclusion

All together, findings to date from scientific, medical, and journalistic investigations combine to demonstrate that fracking poses significant threats to air, water, health, public safety, climate stability, seismic stability, community cohesion, and long-term economic vitality. Emerging data from a rapidly expanding body of evidence continue to reveal a plethora of recurring problems and harms that cannot be sufficiently averted through regulatory frameworks. There is no evidence that fracking can operate without threatening public health directly or without imperiling climate stability upon which public health depends. In the words of investigative journalist Andrew Nikiforuk:

> Industry swore that its cracking rock technology was safe and proven, but science now tells a different story. Brute force combined with ignorance … has authored thousands of earthquakes … [and] called forth clouds of migrating methane…. The science is complicated but clear: cracking rock with fluids is a chaotic activity and no computer model can predict where those fractures will go. The regulatory record shows that they often go out of zone; extend into water; and rattle existing oil and gas wells, and these rattled wells are leaking more methane.[1123]

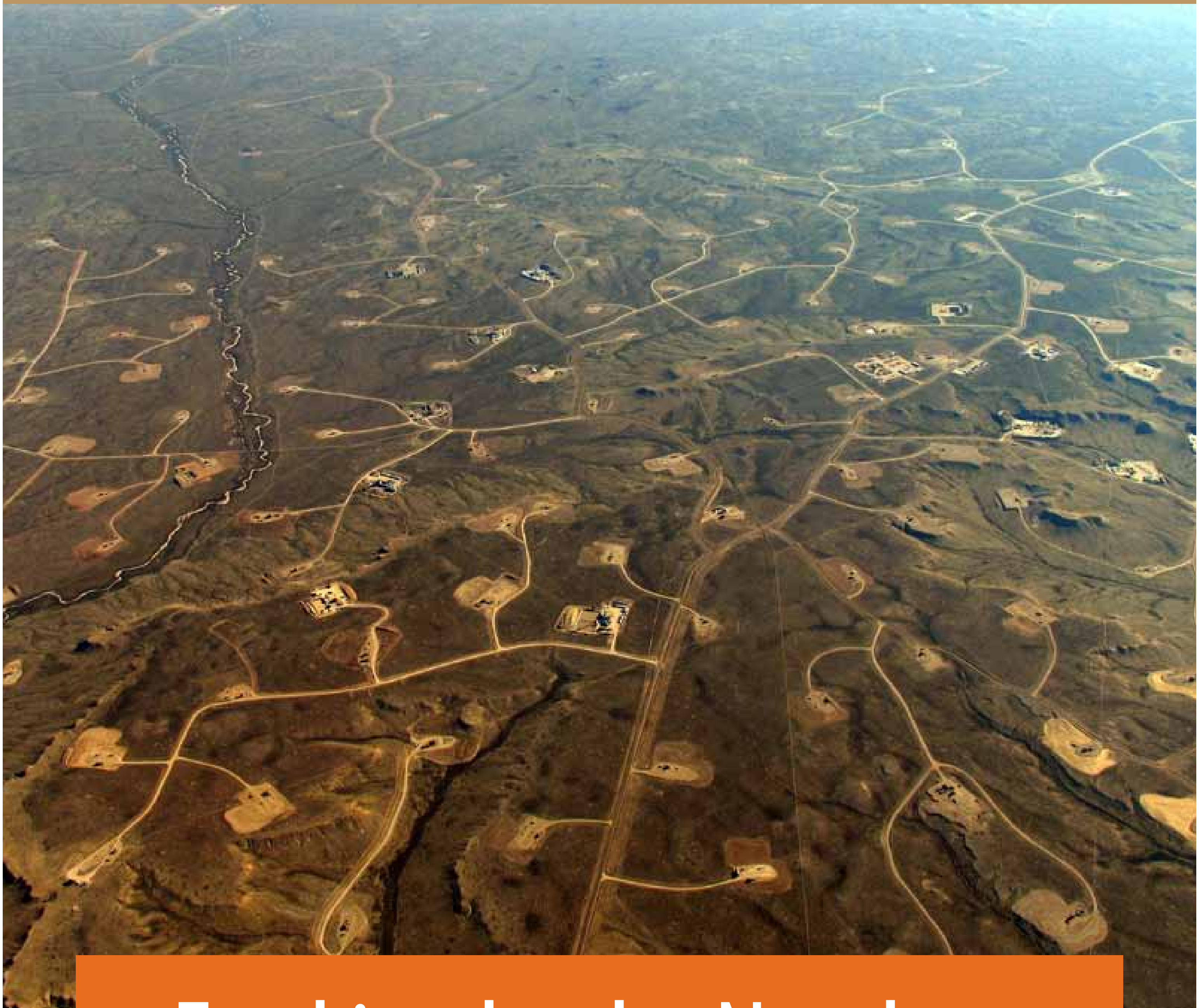
We close with an observation by Maryland physician Judy Stone, MD, whose recent essay in *Forbes* speaks for all who have contributed to this Compendium:

> Fracking profits go to private industry but the public—families and communities—bear the costs of the many health complications from the drilling.
>
> There is growing evidence of a variety of health problems being associated with fracking. Common sense dictates that drinking and breathing cancer-causing agents will take their toll. The correlation is too strong to ignore, especially when we have other, cleaner energy options. For our safety and that of future generations, we should not allow the new administration to sell off public lands, nor allow drilling on our land, and should ban fracking completely.[1124]

[1123] Nikiforuk, A. (2016, October 16). Acceptance speech, USA National Science in Society Journalism Awards reception, San Antonio, Texas. Retrieved from http://www.ernstversusencana.ca/andrew-nikiforuk-wins-usa-national-science-in-society-award-slick-water-nasws-awards-honor-outstanding-investigative-interpretive-reporting-sciences-their-impact-for-good-and-ill/

[1124] Stone, J. (2017, February 23). Fracking is dangerous to your health—here's why. *Forbes*. Retrieved from https://www.forbes.com/sites/judystone/2017/02/23/fracking-is-dangerous-to-your-health-heres-why/#82aa5c75945f

Exhibit 11



Fracking by the Numbers

Key Impacts of Dirty Drilling at the State and National Level

ENVIRONMENT AMERICA
RESEARCH & POLICY CENTER

Fracking by the Numbers

Key Impacts of Dirty Drilling at the State and National Level

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October 2013

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Executive Summary

Over the past decade, the oil and gas industry has fused two technologies—hydraulic fracturing and horizontal drilling—in a highly polluting effort to unlock oil and gas in underground rock formations across the United States.

As fracking expands rapidly across the country, there are a growing number of documented cases of drinking water contamination and illness among nearby residents. Yet it has often been difficult for the public to grasp the scale and scope of these and other fracking threats. Fracking is already underway in 17 states, with more than 80,000 wells drilled or permitted since 2005. Moreover, the oil and gas industry is aggressively seeking to expand fracking to new states—from New York to California to North Carolina—and to areas that provide drinking water to millions of Americans.

This report seeks to quantify some of the key impacts of fracking to date—including the production of toxic wastewater, water use, chemicals use, air pollution, land damage and global warming emissions.

To protect our states and our children, states should halt fracking.

Toxic wastewater: Fracking produces enormous volumes of toxic wastewater—often containing cancer-causing and even radioactive material. Once brought to the surface, this toxic waste poses hazards for drinking water, air quality and public safety:

- Fracking wells nationwide produced an estimated 280 billion gallons of wastewater in 2012.
- This toxic wastewater often contains cancer-causing and even radioactive materials, and has contaminated drinking water sources from Pennsylvania to New Mexico.
- Scientists have linked underground injection of wastewater to earthquakes.
- In New Mexico alone, waste pits from all oil and gas drilling have contaminated groundwater on more than 400 occasions.

Table ES-1. National Environmental and Public Health Impacts of Fracking

Fracking Wells since 2005	82,000
Toxic Wastewater Produced in 2012 (billion gallons)	280
Water Used since 2005 (billion gallons)	250
Chemicals Used since 2005 (billion gallons)	2
Air Pollution in One Year (tons)	450,000
Global Warming Pollution since 2005 (million metric tons CO_2-equivalent)	100
Land Directly Damaged since 2005 (acres)	360,000

Water use: Fracking requires huge volumes of water for each well.

- Fracking operations have used at least 250 billion gallons of water since 2005. (See Table ES-2.)
- While most industrial uses of water return it to the water cycle for further use, fracking converts clean water into toxic wastewater, much of which must then be permanently disposed of, taking billions of gallons out of the water supply annually.
- Farmers are particularly impacted by fracking water use as they compete with the deep-pocketed oil and gas industry for water, especially in drought-stricken regions of the country.

Chemical use: Fracking uses a wide range of chemicals, many of them toxic.

- Operators have hauled more than 2 billion gallons of chemicals to thousands of fracking sites around the country.
- In addition to other health threats, many of these chemicals have the potential to cause cancer.
- These toxics can enter drinking water supplies from leaks and spills, through well blowouts, and through the failure of disposal wells receiving fracking wastewater.

Table ES-2. Water Used for Fracking, Selected States

State	Total Water Used since 2005 (billion gallons)
Arkansas	26
Colorado	26
New Mexico	1.3
North Dakota	12
Ohio	1.4
Pennsylvania	30
Texas	110
West Virginia	17

Air pollution: Fracking-related activities release thousands of tons of health-threatening air pollution.

- Nationally, fracking released 450,000 tons of pollutants into the air that can have immediate health impacts.
- Air pollution from fracking contributes to the formation of ozone "smog," which reduces lung function among healthy people, triggers asthma attacks, and has been linked to increases in school absences, hospital visits and premature death. Other air pollutants from fracking and the fossil-fuel-fired machinery used in fracking have been linked to cancer and other serious health effects.

Global warming pollution: Fracking produces significant volumes of global warming pollution.

- Methane, which is a global warming pollutant 25 times more powerful than carbon dioxide, is released at multiple steps during fracking, including during hydraulic fracturing and well completion, and in the processing and transport of gas to end users.
- Global warming emissions from completion of fracking wells since 2005 total an estimated 100 million metric tons of carbon dioxide equivalent.

Damage to our natural heritage: Well pads, new access roads, pipelines and other infrastructure turn forests and rural landscapes into industrial zones.

- Infrastructure to support fracking has damaged 360,000 acres of land for drilling sites, roads and pipelines since 2005.
- Forests and farmland have been replaced by well pads, roads, pipelines and other gas infrastructure, resulting in the loss of wildlife habitat and fragmentation of remaining wild areas.

- In Colorado, fracking has already damaged 57,000 acres of land, equal to one-third of the acreage in the state's park system.
- The oil and gas industry is seeking to bring fracking into our national forests, around several of our national parks, and in watersheds that supply drinking water to millions of Americans.

Fracking has additional impacts not quantified here—including contamination of residential water wells by fracking fluids and methane leaks; vehicle and workplace accidents, earthquakes and other public safety risks; and economic and social damage including ruined roads and damage to nearby farms.

Defining "Fracking"

In this report, when we refer to the impacts of "fracking," we include impacts resulting from all of the activities needed to bring a shale gas or oil well into production using high-volume hydraulic fracturing (fracturing operations that use at least 100,000 gallons of water), to operate that well, and to deliver the gas or oil produced from that well to market. The oil and gas industry often uses a more restrictive definition of "fracking" that includes only the actual moment in the extraction process when rock is fractured—a definition that obscures the broad changes to environmental, health and community conditions that result from the use of fracking in oil and gas extraction.

To address the environmental and public health threats from fracking across the nation:

- States should prohibit fracking. Given the scale and severity of fracking's myriad impacts, constructing a regulatory regime sufficient to protect the environment and public health from dirty drilling—much less enforcing such safeguards at more than 80,000 wells, plus processing and waste disposal sites across the country—seems implausible. In states where fracking is already underway, an immediate moratorium is in order. In all other states, banning fracking is the prudent and necessary course to protect the environment and public health.
- Given the drilling damage that state officials have allowed fracking to incur thus far, at a minimum, federal policymakers must step in and close the loopholes exempting fracking from key provisions of our nation's environmental laws.
- Federal officials should also protect America's natural heritage by keeping fracking away from our national parks, national forests, and sources of drinking water for millions of Americans.
- To ensure that the oil and gas industry—rather than taxpayers, communities or families—pays the costs of fracking damage, policymakers should require robust financial assurance from fracking operators at every well site.
- More complete data on fracking should be collected and made available to the public, enabling us to understand the full extent of the harm that fracking causes to our environment and health.

Introduction

Many Americans have an image of the damage caused by fracking. Documentaries and YouTube videos have shown us tap water catching on fire and families experiencing headaches, dizziness, nausea and other illnesses while living near fracking operations. Plane trips over Texas or Colorado reveal the grids of wells across the landscape.

These snapshots illustrate the damage that fracking does to the environment and our health. But, until now, it has been difficult to comprehend the cumulative extent of that damage. Individual fracking wells, we know, can pollute the air and water of a neighborhood or town. But what does it mean now that the nation has not dozens or hundreds but tens of thousands of fracking wells in at least 17 states? What, for example, is the magnitude of the risk those wells present to drinking water? How many iconic landscapes are being damaged?

In this report, we have quantified several of the key impacts of fracking on water, air and land, at the state and national level, using the best available sources of information on the extent of fracking and the impacts of fracking on our environment and health.

Our analysis shows that damage from fracking is widespread and occurs on a scale unimagined just a few years ago. Moreover, three factors suggest that the total damage from fracking is far worse than we have tabulated here. Severe limitations in available data constrain our ability to see the full extent of the damage. Second, there are broad categories of fracking damage—such as the number of water wells contaminated—that would be difficult to ascertain under any circumstances. Finally, there remain major gaps in the scientific community's understanding of issues such as the long-term consequences of pumping toxic fluids into the ground.

Even the limited data that are currently available, however, paint an increasingly clear picture of the damage that fracking has done to our environment and health. It will take decisive action to protect the American people and our environment from the damage caused by dirty drilling.

Our analysis shows that damage from fracking is widespread and occurs on a scale unimagined just a few years ago.

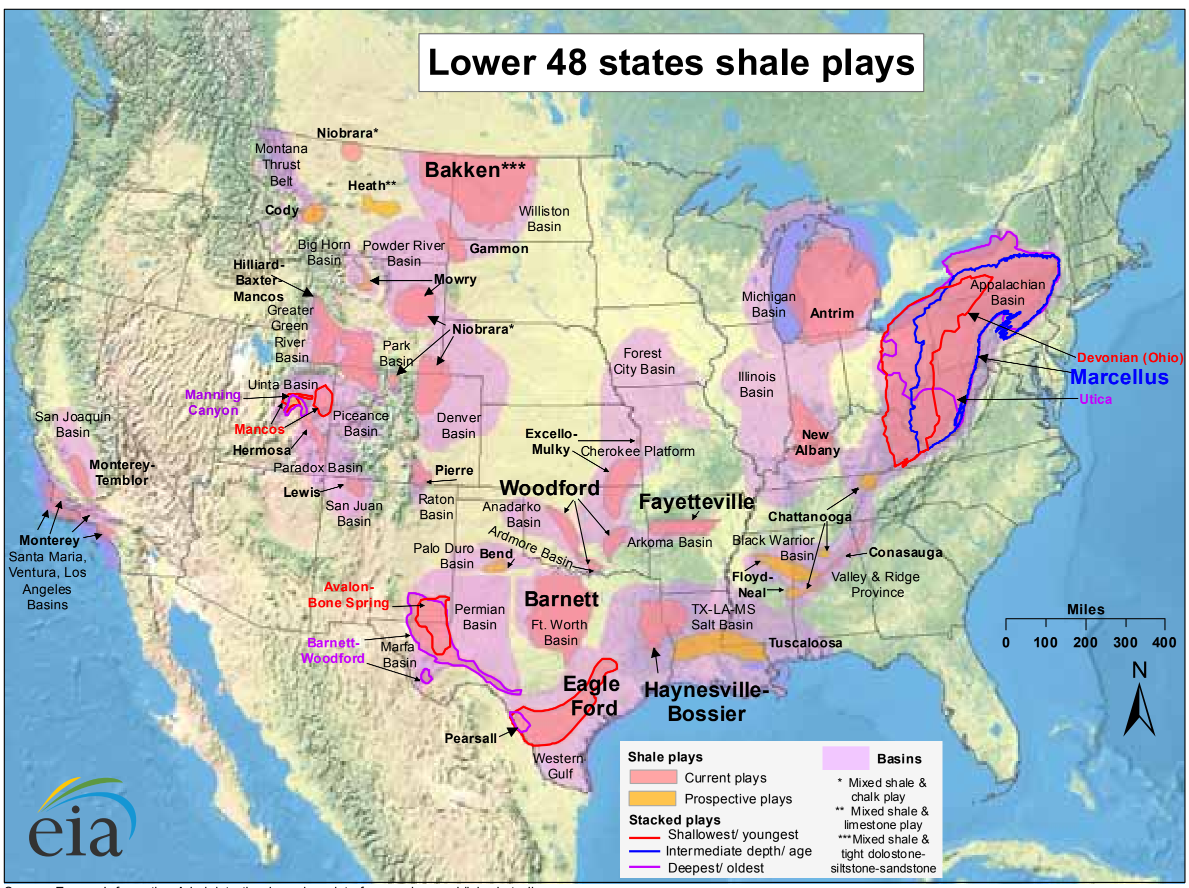
Fracking Poses Grave Threats to the Environment and Public Health

Over the past decade, the oil and gas industry has used hydraulic fracturing to extract oil and gas from previously inaccessible rock formations deep underground. The use of high-volume hydraulic fracturing—colloquially known as "fracking"—has expanded dramatically from its origins in the Barnett Shale region of Texas a decade ago to tens of thousands of wells nationwide today.

Roughly half of U.S. states, stretching from New York to California, sit atop shale or other rock formations with the potential to produce oil or gas using fracking. (See Figure 1.)

Fracking has unleashed a frenzy of oil and gas drilling in several of these shale formations—posing severe threats to the environment and public health.

Figure 1. Shale Gas and Oil Plays[1]



Source: Energy Information Administration based on data from various published studies.
Updated: May 9, 2011

Contaminating Drinking Water

Fracking has polluted both groundwater and surface waterways such as rivers, lakes and streams. Fracking pollution can enter our waters at several points in the process—including leaks and spills of fracking fluid, well blowouts, the escape of methane and other contaminants from the well bore into groundwater, and the long-term migration of contaminants underground. Handling of toxic fracking waste that returns to the surface once a well has been fracked presents more opportunities for contamination of drinking water. State data confirm more than 1,000 cases of water contaminated by dirty drilling operations. For example:

- In Colorado, approximately 340 of the leaks or spills reported by drilling operators engaged in all types of oil and gas drilling over a five-year period polluted groundwater;[2]
- In Pennsylvania, state regulators identified 161 instances in which drinking water wells were impacted by drilling operations between 2008 and the fall of 2012;[3] and
- In New Mexico, state records show 743 instances of all types of oil and gas operations polluting groundwater—the source of drinking water for 90 percent of the state's residents.[4]

Spills and Leaks of Fracking Fluids

Toxic substances in fracking chemicals and wastewater have been linked to a variety of negative health effects on humans and fish. Chemical components of fracking fluids, for example, have been linked to cancer, endocrine disruption and neurological and immune system problems.[5] Wastewater brought to the surface by drilling can contain substances such as volatile organic compounds with potential impacts on human health.[6]

There are many pathways by which fracking fluids can contaminate drinking water supplies. Spills from trucks, leaks from other surface equipment, and well blowouts can release polluted water to groundwater and surface water. For example, in September 2009 Cabot Oil and Gas caused three spills in Dimock Township, Pennsylvania, in less than a week, dumping 8,000 gallons of fracturing fluid components into Stevens Creek and a nearby wetland.[7]

Leaks of Methane and Other Contaminants from the Well Bore

A study by researchers at Duke University found that the proximity of drinking water wells to fracking wells increases the risk of contamination of residential wells with methane in Pennsylvania. The researchers pointed to faulty well casing as a likely source.[8] Data from fracking wells in Pennsylvania from 2010 to 2012 show a 6 to 7 percent well failure rate due to compromised structural integrity.[9]

Migration of Contaminants

A recent study of contamination in drinking water wells in the Barnett Shale area of North Texas found arsenic, selenium and strontium at elevated levels in drinking water wells close to fracking sites.[10] The researchers surmise that fracking has increased pollution in drinking water supplies by freeing naturally available chemicals to move into groundwater at higher concentrations or through leaks from faulty well construction.

Toxic Fracking Waste

The wastewater produced from fracking wells contains pollutants both from fracking fluids and from natural sources underground. It returns to the surface in huge volumes—both as "flowback" immediately after fracking and "produced water" over a longer period while a well is producing oil or gas. Yet fracking operators have no safe, sustainable way of dealing with this toxic waste. The approaches that drilling companies have devised for dealing with wastewater can pollute waterways through several avenues.

- Waste pits can fail. In New Mexico, substances from oil and gas pits have contaminated groundwater at least 421 times.[11] Moreover, waste pits also present hazards for nearby wildlife and livestock. For example, in May 2010, when a Pennsylvania fracturing wastewater pit owned by East Resources leaked into a farm field, the state Department of Agriculture was forced to quarantine 28 cattle exposed to the fluid to prevent any contaminated meat from reaching the market.[12]

- Discharge of fracking wastewater into rivers can pollute drinking water supplies. For example, after water treatment plants discharged fracking wastewater into the Monongahela River, local authorities issued a drinking water advisory to 350,000 people in the area.[13] In addition, fracking wastewater discharged at treatment plants can cause a different problem for drinking water: when bromide in the wastewater mixes with chlorine (often used at drinking water treatment plants), it produces trihalomethanes, chemicals that cause cancer and increase the risk of reproductive or developmental health problems.[14]

- Drilling companies deliberately spread wastewater on roads and fields. Pollutants from the water can then contaminate local waterways. Drilling operators sometimes spray wastewater on dirt and gravel roads to control dust, or on paved roads to melt ice. In some Western states, fracking waste is spread on farmland or used to water cattle.[15]

- Deep disposal wells are a common destination for fracking waste, but these wells can fail over time, allowing the wastewater and its pollutants to mix with groundwater or surface water.[16] For example,

Photo: The Downstream Project via SkyTruth/LightHawk.

Fracking wastewater is often stored in open waste pits such as these, near Summit, Pennsylvania. Leaks from pits can contaminate drinking water supplies.

wastewater injected into a disposal well contaminated the Cenozoic Pecos Alluvium Aquifer with 6.2 billion gallons of water near Midland, Texas.[17] In Pennsylvania, a disposal well in Bell Township, Clearfield County, lost mechanical integrity in April 2011, but the operator, EXCO Resources, continued to inject fracking wastewater into the well for another five months.[18] The U.S. Environmental Protection Agency (EPA) fined the company nearly $160,000 for failing to protect drinking water supplies. Nationally, routine testing of injection wells in 2010 revealed that 2,300 failed to meet mechanical integrity requirements established by the EPA.[19]

- Pressure from injection wells may cause underground rock layers to crack, accelerating the migration of wastewater into drinking water aquifers. For example, at two injection wells in Ohio, toxic chemicals pumped underground in the 1980s, supposedly secure for at least 10,000 years, migrated into a well within 80 feet of the surface over the course of two decades.[20] Investigators believe that excessive pressure within the injection well caused the rock to fracture, allowing chemicals to escape.

Despite the risk presented to drinking water supplies by fracking, the oil and gas industry is seeking to drill near sources of drinking water for millions of people, including George Washington National Forest in Virginia, White River National Forest in Colorado, Otero Mesa in New Mexico, Wayne National Forest in Ohio, and the Delaware River Basin.

Consuming Scarce Water Resources

Each well that is fracked requires hundreds of thousands of gallons of water depending on the shale formation and the depth and length of the horizontal portion of the well. Unlike most industrial uses of water which return water to the water cycle for further use, fracking converts clean water into toxic wastewater, much of which must then be permanently disposed of, taking billions of gallons out of the water supply annually. Moreover, farmers are particularly impacted by fracking water use, as they must now compete with the deep-pocketed oil and gas industry for water, especially in the drought-stricken regions of the country.

In some areas, fracking makes up a significant share of overall water demand. In 2010, for example, fracking in the Barnett Shale region of Texas consumed an amount of water equivalent to 9 percent of the city of Dallas' annual water use.[21] An official at the Texas Water Development Board estimated that one county in the Eagle Ford Shale region will see the share of water consumption devoted to fracking and similar activities increase from zero a few years ago to *40 percent* by 2020.[22] Unlike other uses, water used in fracking is permanently lost to the water cycle, as it either remains in the well, is "recycled" (used in the fracking of new wells), or is disposed of in deep injection wells, where it is unavailable to recharge aquifers.

Already, demand for water by oil and gas companies has harmed farmers and local communities:

- In Texas, water withdrawals by drilling companies caused drinking water wells in the town of Barnhart to dry up. Companies drilling in the Permian Basin have drilled wells and purchased well water drawn from the Edwards-Trinity-Plateau Aquifer, drying up water supplies for residential and agricultural use.[23]
- Wells that provided water to farms near Carlsbad, New Mexico, have gone dry due to demand for water for drilling and years of low rainfall.[24]

Competition for limited water resources from fracking can increase water prices for farmers and communities—especially in arid western states. A 2012 auction of unallocated water conducted by the

Northern Water Conservation District in Colorado saw gas industry firms submit high bids, with the average price of water sold in the auction increasing from $22 per acre-foot in 2010 to $28 per acre-foot in the first part of 2012.[25] For the 25,000 acre-feet of water auctioned, this would amount to an added cost of $700,000.

Moreover, water pumped from rivers for fracking reduces the quality of the water remaining in the river because pollution becomes more concentrated. A 2011 U.S. Army Corps of Engineers study of the Monongahela River basin of Pennsylvania and West Virginia, where oil and gas companies withdraw water from the river for fracking, concluded that, "The quantity of water withdrawn from streams is largely unregulated and is beginning to show negative consequences."[26] The Corps report noted that water is increasingly being diverted from the relatively clean streams that flow into Corps-maintained reservoirs, limiting the ability of the Corps to release clean water to help dilute pollution during low-flow periods.[27] It described the water supply in the Monongahela basin as "fully tapped."[28]

Excessive water withdrawals undermine the ability of rivers and streams to support wildlife. In Pennsylvania, water has been illegally withdrawn for fracking numerous times, to the extent of streams being sucked dry. Two streams in southwestern Pennsylvania—Sugarcamp Run and Cross Creek—were reportedly drained for water withdrawals for fracking, triggering fish kills.[29]

Nationally, nearly half of all fracking wells are located in regions with very limited water supplies. A study by Ceres, a coalition of business and environmental interests, found that nearly 47 percent of wells fracked from January 2011 through September 2012 were located in areas with "high or extremely high water stress."[30]

Endangering Public Health with Air Pollution

Air pollution from fracking threatens the health of people living and working close to the wellhead, as well as those far away. Children, the elderly and those with respiratory diseases are especially at risk.

Fracking produces air pollution from the well bore as the well is drilled and gas is vented or flared. Emissions from trucks carrying water and materials to well sites, as well as from compressor stations and other fossil fuel-fired machinery, also contribute to air pollution. Well operations, storage of gas liquids, and other activities related to fracking add to the pollution toll.

Making Local Residents Sick

People who live close to fracking sites are exposed to a variety of air pollutants including volatile organic compounds (VOCs) such as benzene, xylene and toluene. These chemicals can cause a wide range of health problems—from eye irritation and headaches to asthma and cancer.[31]

Existing data demonstrate that fracking operations are releasing these pollutants into the air at levels that threaten our health. In Texas, monitoring by the Texas Department of Environmental Quality detected levels of benzene—a known cancer-causing chemical—in the air that were high enough to cause immediate human health concern at two sites in the Barnett Shale region, and at levels that pose long-term health concern at an additional 19 sites. Several chemicals were also found at levels that can cause foul odors.[32] Air monitoring in Arkansas has also found elevated levels of volatile organic compounds (VOCs)—some of which are also hazardous air pollutants—at the perimeter of hydraulic fracturing sites.[33] Local air pollution problems have also cropped up in Pennsylvania. Testing conducted by the Pennsylvania Department of Environmental Protection detected components of gas in the air near Marcellus Shale drilling operations.[34]

Residents living near fracking sites have long suffered from a range of acute and chronic health problems, including headaches, eye irritation, respiratory problems and nausea.[35] An investigation by the journalism website ProPublica uncovered numerous reports of illness in western states from air pollution from fracking.[36] In Pennsylvania, a homeowner in the town of Carmichaels described how she and her children began to suffer from a variety of symptoms after a compressor station was built 780 feet from her house.[37] Pam Judy explained to the nearby Murrysville Council that "Shortly after operations began, we started to experience extreme headaches, runny noses, sore/scratchy throats, muscle aches and a constant feeling of fatigue. Both of our children are experiencing nose bleeds and I've had dizziness, vomiting and vertigo to the point that I couldn't stand and was taken to an emergency room." Eventually, she convinced state officials to test air quality near her home. That testing revealed benzene, styrene, toluene, xylene, hexane, heptane, acetone, acrolein, carbon tetrachloride and chloromethane in the air.[38]

All indications are that these known stories just scratch the surface of health damage from fracking. In cases where families made sick from fracking have sought to hold drilling companies accountable in court, the companies have regularly insisted on gag orders as conditions of legal settlements—in a recent case even the children were barred from talking about fracking, for life.[39]

Workers at drilling sites also suffer from health impacts. A recent investigation by the National Institute for Occupational Safety and Health (NIOSH) found that workers at some fracking sites may be at risk of lung disease as a result of inhaling silica dust from sand injected into wells. The NIOSH investigation reviewed 116 air samples at 11 fracking sites in Arkansas, Colorado, North Dakota, Pennsylvania and Texas. Nearly half (47 percent) of the samples had levels of silica that exceeded the Occupational Safety and Health Administration's (OSHA) legal limit for workplace exposure, while 78 percent exceeded OSHA's recommended limits. Nearly one out of 10 (9%) of the samples exceeded the legal limit for silica by a factor of 10, exceeding the threshold at which half-face respirators can effectively protect workers.[40]

Over the past few years, health clinics in fracking areas of Pennsylvania have reported seeing a number of patients experiencing illnesses associated with exposure to toxic substances from fracking, all of whom have used false names and paid in cash. David Brown, a toxicologist with the Southwest Pennsylvania Environmental Health Project believes that these are mostly fracking workers, who are afraid that any record of their work making them sick will cost them their jobs.[41]

Regional Air Pollution Threats

Fracking also produces a variety of pollutants that contribute to regional air pollution problems. VOCs and nitrogen oxides (NO_x) in gas formations contribute to the formation of ozone "smog," which reduces lung function among healthy people, triggers asthma attacks, and has been linked to increases in school absences, hospital visits and premature death.[42]

Fracking is a significant source of air pollution in areas experiencing large amounts of drilling. A 2009 study in five Dallas-Fort Worth-area counties experiencing heavy Barnett Shale drilling activity found that oil and gas production was a larger source of smog-forming emissions than cars and trucks.[43] In Arkansas, gas production in the Fayetteville Shale region was estimated to be responsible for 5,000 tons of NO_x.[44] In Wyoming, pollution from fracking contributed to such poor air quality that, for the first time, the state failed to meet federal air quality standards.[45] An analysis conducted for New York State's revised draft environmental impact statement on Marcellus Shale drilling posited that, in a worst case scenario of widespread drilling and lax emission controls, shale gas production could add 3.7 percent to state NO_x emissions and 1.3 percent to statewide VOC emissions compared with 2002 emissions levels.[46]

Exacerbating Global Warming

Global warming is a profound threat to virtually every aspect of nature and human civilization—disrupting the functioning of ecosystems, increasing the frequency and violence of extreme weather, and ultimately jeopardizing health, food production, and water resources for Americans and people across the planet. Gas extraction produces enormous volumes of global warming pollution.

Fracking's primary impact on the climate is through the release of methane, which is a far more potent contributor to global warming than carbon dioxide. Over a 100-year timeframe, a pound of methane has 25 times the heat-trapping effect of a pound of carbon dioxide.[47] Methane is even more potent relative to carbon dioxide at shorter timescales, at least 72 times more over a 20-year period.

Intentional venting and leaks during the extraction, transmission and distribution of gas release substantial amounts of methane to the atmosphere. The U.S. Environmental Protection Agency revised downward its estimate of fugitive methane emissions from fracking in April 2013, citing improved practices by the industry.[48] A study conducted with industry cooperation and released in September 2013 found very low fugitive emissions of methane at the wells included in the study, though the findings may not be representative of standard industry practice.[49]

However, recent air monitoring by researchers at the National Oceanic and Atmospheric Administration and the University of Colorado, Boulder, near a gas and oil field in Colorado revealed fugitive methane emissions equal to 2.3 to 7.7 percent of the gas extracted in the basin, not counting the further losses that occur in transportation.[50] Recent aerial sampling of emissions over an oil and gas field in Uintah County, Utah, revealed methane emissions equal to 6.2 to 11.7 percent of gas production.[51]

The global warming impact of fracked natural gas is so great that electricity produced from natural gas may have a greater global warming impact than electricity from coal, especially when evaluated on a short timeline. An analysis by Professor Robert Howarth at Cornell and others found that, on a 20-year timescale, electricity from natural gas is more polluting than electricity from coal.[52]

Regardless of the fugitive emissions level from fracked gas, increased production of and reliance on gas is not a sound approach to reducing our global warming emissions. Investments in gas production and distribution infrastructure divert financing and efforts away from truly clean energy sources such as energy efficiency and wind and solar power. Gas is not a "bridge fuel" that prepares us for a clean energy future; rather, increasing our use of gas shifts our reliance from one polluting fuel to another.

Additionally, to the extent that fracking produces oil instead of gas, fracking does nothing to reduce global warming pollution: in fact, refining oil into useable products like gasoline and diesel, and then burning those products, is a huge source of global warming pollution.

Damaging America's Natural Heritage

Fracking transforms rural and natural areas into industrial zones. This development threatens national parks and national forests, damages the integrity of landscapes and habitats, and contributes to water pollution problems that threaten aquatic ecosystems.

Before drilling can begin, land must be cleared of vegetation and leveled to accommodate drilling equipment, gas collection and processing equipment, and vehicles. Additional land must be cleared for roads to the well site, as well as for any pipelines and compressor stations needed to deliver gas to market. A study by the Nature Conservancy of fracking infrastructure in Pennsylvania found that well pads average 3.1 acres and related infrastructure damages an additional 5.7 acres.[53] Often, this development occurs on remote and previously undisturbed wild lands.

As oil and gas companies expand fracking activities, national parks, national forests and other iconic landscapes are increasingly at risk. Places the industry is seeking to open for fracking include:

- **White River National Forest** – Located in Colorado, this forest draws 9.2 million visitors per year for hiking, camping and other recreation, making it the most visited national forest in the country.[54] The forest also hosts 4,000 miles of streams that provide water to several local communities and feed into the Colorado River.
- **Delaware River Basin** – This basin, which spans New Jersey, New York, Pennsylvania and Delaware, is home to three national parks and provides drinking water to 15 million people.[55]
- **Wayne National Forest** – Part of Ohio's beautiful Hocking Hills region, most of the acres in the forest are to be leased for drilling near the sole drinking water source for 70,000 people.[56]

Photo: Peter Aengst via SkyTruth/EcoFlight.

Wells and roads built to support fracking in Wyoming's Jonah gas field have caused extensive habitat fragmentation.

- **George Washington National Forest** – This area hosts streams in Virginia and West Virginia that feed the James and Potomac Rivers, which provide the drinking water for millions of people in the Washington, D.C., metro area.
- **Otero Mesa** – A vital part of New Mexico's natural heritage, Otero Mesa is home to pronghorn antelope and a freshwater aquifer that could be a major source of drinking water in this parched southwestern state.[57]

The disruption and fragmentation of natural habitat can put wildlife at risk. In Wyoming, for example, extensive gas development in the Pinedale Mesa region has coincided with a significant reduction in the region's population of mule deer. A 2006 study found that the construction of well pads drove away female mule deer.[58] The mule deer population in the area dropped by 50 percent between 2001 and 2011, as fracking in the area continued and accelerated.[59]

Concerns have also been raised about the impact of gas development on pronghorn antelope. A study by the Wildlife Conservation Society documented an 82 percent reduction in high-quality pronghorn habitat in Wyoming's gas fields, which have historically been key wintering grounds.[60]

Birds may also be vulnerable, especially those that depend on grassland habitat. Species such as the northern harrier, short-eared owl, bobolink, upland sandpiper, loggerhead shrike, snowy owl, rough-legged hawk and American kestrel rely on grassland habitat for breeding or wintering habitat.[61] These birds typically require 30 to 100 acres of undisturbed grassland for habitat.[62] Roads, pipelines and well pads for fracking may fragment grassland into segments too small to provide adequate habitat.

The clearing of land for well pads, roads and pipelines may threaten aquatic ecosystems by increasing sedimentation of nearby waterways and decreasing shade. A study by the Academy of Natural Sciences of Drexel University found an association between increased density of gas drilling activity and degradation of ecologically important headwater streams.[63]

Water contamination related to fracking has caused several fish kills in Pennsylvania. In 2009, a pipe containing freshwater and flowback water ruptured in Washington County, Pennsylvania, triggering a fish kill in a tributary of Brush Run, which is part of a high-quality watershed.[64] That same year, in the same county, another pipe ruptured at a well drilled in a public park, killing fish and other aquatic life along a three-quarter-mile length of a local stream.[65]

Imposing Costs on Communities

As with prior extractive booms, the fracking oil and gas rush disrupts local communities and imposes a wide range of immediate and long term costs on them.

Ruining Roads, Straining Services

As a result of its heavy use of publicly available infrastructure and services, fracking imposes both immediate and long-term costs on taxpayers.

The trucks required to deliver water to a single fracking well cause as much damage to roads as 3.5 million car journeys, putting massive stress on roadways and bridges not constructed to handle such volumes of heavy traffic. Pennsylvania estimates that repairing roads affected by Marcellus Shale drilling would cost $265 million.[66]

Fracking also strains public services. Increased heavy vehicle traffic has contributed to an increase in traffic accidents in drilling regions. At the same time, the influx of temporary workers that typically accompanies fracking puts pressure on housing supplies, thereby causing social dislocation. Governments respond by increasing their spending on social services and subsidized housing, squeezing tax-funded budgets.

Governments may even be forced to spend tax money to clean up orphaned wells—wells that were never properly closed and whose owners, in many cases, no longer exist as functioning business entities. Though oil and gas companies face a legal responsibility to plug wells and reclaim drilling sites, they have a track record of leaving the public holding the bag.[67]

Risks to Local Businesses, Homeowners and Taxpayers

Fracking imposes damage on the environment, public health and public infrastructure, with significant economic costs, especially in the long run after the initial rush of drilling activity has ended. A 2008 study by the firm Headwaters Economics found that Western counties that have relied on fossil-fuel extraction for growth are doing worse economically than their peers, with less-diversified economies, a less-educated workforce, and greater disparities in income.[68]

Other negative impacts on local economies include downward pressure on home values and harm to farms. Pollution, stigma and uncertainty about the future implications of fracking can depress the prices of nearby properties. One Texas study found that homes valued at more than $250,000 and located within 1,000 feet of a well site lost 3 to 14 percent of their value.[69] Fracking also has the potential to affect agriculture, both directly through damage to livestock from exposure to fracking fluids, and indirectly through economic changes that undermine local agricultural economies.

Fracking can increase the need for public investment in infrastructure and environmental cleanup. Fracking-related water demand may also lead to calls for increased public spending on water infrastructure. Texas, for example, adopted a State Water Plan in 2012 that calls for $53 billion in investments in the state water system, including $400 million to address unmet needs in the mining sector (which includes hydraulic fracturing) by 2060.[70] Fracking is projected to account for 42 percent of water use in the Texas mining sector by 2020.[71]

The cost of cleaning up environmental damage from the current oil and gas boom may fall to taxpayers, as has happened with past booms. For example, as of 2006, more than 59,000 orphan oil and gas wells were on state waiting lists for plugging and remediation across the United States, with at least an additional 90,000 wells whose status was unknown or undocumented.[72] Texas alone has more than 7,800 orphaned oil and gas wells.[73] These wells pose a continual threat of groundwater pollution and have cost the state of Texas more than $247 million to plug.[74] The current fracking boom ultimately may add to this catalog of orphaned wells.

Threatening Public Safety

Fracking harms public safety by increasing traffic in rural areas where roads are not designed for such high volumes, by creating an explosion risk from methane, and by increasing earthquake activity.

Increasing traffic—especially heavy truck traffic—has contributed to an increase in traffic accidents and fatalities in some areas in which fracking has unleashed a drilling boom, as well as an increase in demands for emergency response. In the Bakken Shale oil region of North Dakota for example, the number of highway crashes increased by 68 percent between 2006 and 2010, with the share of crashes involving heavy trucks also increasing over that period.[75] A 2011 survey by StateImpact Pennsylvania in eight counties found that 911 calls had increased in seven of them, with the number of calls increasing in one county by 49 percent over three years, largely due to an increase in incidents involving heavy trucks.[76]

Methane contamination of well water poses a risk of explosion if the gas builds up inside homes. In both Ohio and Pennsylvania, homes have exploded after high concentrations of methane inside the buildings were ignited by a spark.[77]

Another public safety hazard stems from earthquakes triggered by injection wells. For example, on New Year's Eve in 2011—shortly after Ohio began accepting increasing amounts of wastewater from Pennsylvania—a 4.0 earthquake shook Youngstown, Ohio. Seismic experts at Columbia University determined that pumping fracking wastewater into a nearby injection well caused the earthquake.[78] Earthquakes triggered by injection well wastewater disposal have happened in Oklahoma, Arkansas, Texas, Ohio and Colorado. The largest quake—a magnitude 5.7 temblor in Oklahoma that happened in 2011—injured two people, destroyed 14 homes and buckled highways. People felt the quake as far as 800 miles away.[79]

As fracking wastewater volumes have increased dramatically since 2007, the number of earthquakes in the central United States, where injection well disposal is common, has increased by more than 1,100 percent compared to earlier decades.[80] Scientists at the U.S. Geological Survey have concluded that humans are likely the cause.[81] After reviewing data on the Oklahoma quake, Dr. Geoffrey Abers, a seismologist at the Lamont-Doherty Earth Observatory, concluded that, "the risk of humans inducing large earthquakes from even small injection activities is probably higher" than previously thought.[82]

Quantifying the State and National Impacts of Fracking

Fracking imposes numerous costly impacts on our environment and public health. This report seeks to estimate several key impacts of fracking for oil and gas, with a primary focus on high-volume fracking.

There have been few, if any, efforts to quantify the cumulative impacts of fracking at a state or national scale. The task is made difficult, in part, by differing definitions and data collection practices for unconventional drilling used in the states. These variations in data make it difficult to isolate high-volume fracking from other practices. To address this challenge, we collected data on unconventional drilling targets (shale gas, shale oil, and tight-gas sands) and practices (horizontal and directional drilling) to ensure the comprehensiveness of the data. Where possible, we then narrowed the data to include only those wells using high-volume hydraulic fracturing involving more than 100,000 gallons of water.

Photo: The Downstream Project via SkyTruth/LightHawk.

More than 6,000 shale gas/liquids wells, such as this well site in Tioga County, have been drilled in Pennsylvania since 2005.

The data presented in the following sections come from multiple sources, including state databases, estimates from knowledgeable state employees, and information provided by oil and gas companies to a national website. As a result, the quality of the data varies and figures may not be directly comparable from state to state. Nonetheless, the numbers paint an initial picture of the extensive environmental and public health damage from fracking.

Table 1. Estimate of Fracking Wells[83]

State	Fracking Wells since 2005	Fracking Wells Drilled in 2012
Arkansas	4,910	719
Colorado	18,168	1,896
Kansas	407	236
Louisiana	2,327	139
Mississippi	9	Unavailable
Montana	264	174
New Mexico	1,353	482
North Dakota	5,166	1,713
Ohio	334	234
Oklahoma	2,694	Unavailable
Pennsylvania	6,651	1,349
Tennessee	30	Unavailable
Texas	33,753	13,540
Utah	1,336	765
Virginia	95	1
West Virginia*	3,275	610
Wyoming	1,126	468
TOTAL	**81,898**	**22,326**

"Unavailable" means information was not available to determine when wells were drilled. See methodology for complete details.

** Data for West Virginia is for permitted fracking wells, not wells that have been drilled. Data were not available on drilled wells.*

Wells Fracked by State

The most basic measure of fracking's scope is a tally of how many fracking wells have been drilled. In addition, having an accurate count of wells by state offers a basis for estimating specific impacts to water, air and land.

Fracking has occurred in at least 17 states (see Table 1), affecting approximately 82,000 wells. In the eastern U.S., Pennsylvania reports the most fracking wells since 2005, with 6,651 wells tapping into the Marcellus and Utica shales. More than 5,000 fracking wells have been drilled in North Dakota to produce oil from the Bakken formation. Western states with the most fracking include Colorado, New Mexico and Utah.

Absent policies to rein in fracking, fracking is likely to expand in these and other states. Tennessee currently has a handful of wells but more will soon be fracked in the Cumberland Forest.[84] One test well was fracked in Georgia in the past year.[85] Illinois recently adopted new regulations governing fracking, paving the way for the practice there.[86] Oil and gas companies are seeking to expand to states such as California, New York, Maryland and North Carolina where there has been no such activity to date. In New York, as many as 60,000 wells could be drilled.[87]

Wastewater Produced

One of the more serious threats fracking poses to drinking water is the millions of gallons of toxic wastewater it generates.

While there are many ways in which fracking can contaminate drinking water—including but not limited to spills of fracking fluid, well blowouts, leaks of methane and other contaminants from the well bore into groundwater, and the possible eventual migration of fluids from shale to the water table—one of the most serious threats comes from the millions of gallons of toxic wastewater fracking generates.

Table 2 shows how much wastewater has been produced from fracking wells in selected states. In some states, such as New Mexico, North Dakota, Ohio, Pennsylvania and Utah, well operators submit regular reports on the volume of wastewater, oil and gas produced from their wells. In some states where operators do not report wastewater volumes, we estimated wastewater volumes using state-specific data as described in the methodology. These estimates are for wastewater only, and do not include other toxic wastes from fracking, such as drilling muds and drill cuttings.

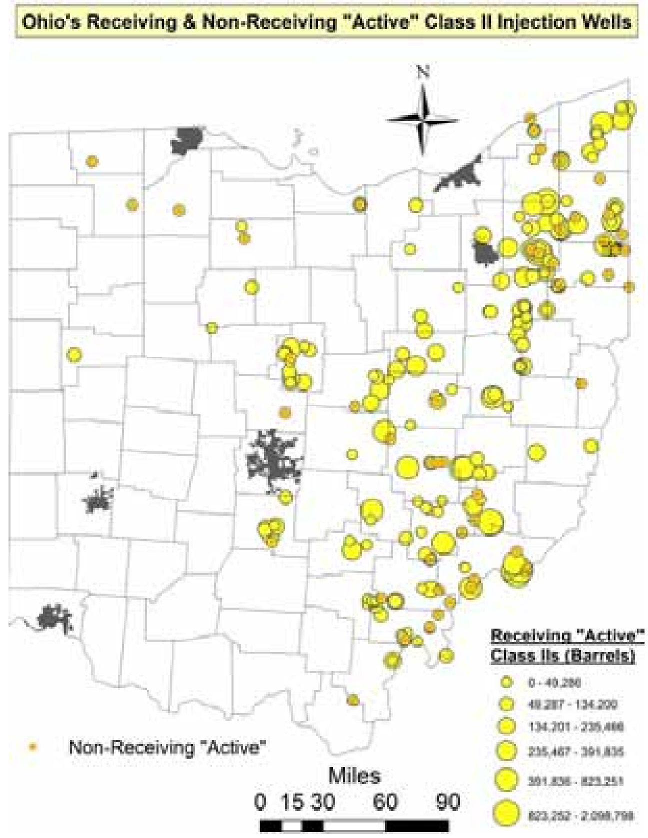
The rapid growth of fracking has caused wastewater volumes to increase rapidly. In the Marcellus Shale underlying Pennsylvania, West Virginia and Ohio, for example, wastewater production increased six-fold from 2004 to 2011.[89]

Table 2. Wastewater from Fracking in 2012[88]

State	Wastewater Produced (million gallons)
Arkansas	800
Colorado	2,200
Kansas	No estimate
Louisiana	No estimate
Mississippi*	10
Montana	360
New Mexico	3,000
North Dakota**	12,000
Ohio	30
Oklahoma	No estimate
Pennsylvania	1,200
Tennessee	No estimate
Texas	260,000
Utah	800
Virginia	No estimate
West Virginia	No estimate
Wyoming	No estimate
TOTAL	**280,000**

** Data for Mississippi are for 2012-2013.*

*** Data for North Dakota are cumulative to early 2013.*



Fracking wastewater is disposed into Class II injection wells in Ohio. "Receiving" wells currently accept fracking wastewater. "Non-receiving" wells are those wells that could receive fracking wastewater but haven't to date. Data mapped by the FracTracker Alliance on FracTracker.org. Original data source: *Bulk Transporter Magazine*, accessed at www.fractracker.org/2013/06/oh-waste-network, 23 July 2013.

In 2012 alone, fracking in Pennsylvania produced 1.2 billion gallons of wastewater, almost as much as was produced in a three-year period from 2009 to 2011.[90]

This huge volume of polluted wastewater creates many opportunities for contaminating drinking water. More wells and more wastewater increase the odds that the failure of a well casing or gasket, a wastewater pit or a disposal well will occur and that drinking water supplies will be contaminated. Moreover, as the sheer volume of wastewater generated exceeds local disposal capacity, drilling operators are increasingly looking to neighboring states as convenient dumping grounds. For example, in 2011, more than 100 million gallons of Pennsylvania's fracking waste were trucked to Ohio for disposal into underground injection wells.[91] (See map of Ohio disposal wells.)

As the volume of this toxic waste grows, so too will the likelihood of illegal dumping. For example, in 2013 Ohio authorities discovered that one drilling waste operator had dumped thousands of gallons of fracking wastewater into the Mahoning River.[92] And in Pennsylvania, prosecutors recently charged a different company with dumping fracking waste.[93]

For other industries, the threats posed by toxic waste have been at least reduced due to the adoption of the federal Resource Conservation Recovery Act (RCRA), which provides a national framework for regulating hazardous waste. Illegal dumping is reduced by cradle-to-grave tracking and criminal penalties. Health-threatening practices such as open waste pits, disposal in ordinary landfills, and road spreading are prohibited. However, waste from oil and gas fracking is exempt from the hazardous waste provisions of RCRA—exacerbating the toxic threats posed by fracking wastewater.

Chemicals Used

Fracking fluid consists of water mixed with chemicals that is pumped underground to frack wells. Though in percentage terms, chemicals are a small component of fracking fluid, the total volume of chemicals used is immense.

The oil and gas industry estimates that 99.2 percent of fracking fluid is water (by volume) and the other 0.8 percent is a mix of chemicals.[94] Assuming that this percentage is correct and has held true since 2005, that means oil and gas companies have used 2 billion gallons of chemicals.

These chemicals routinely include toxic substances. According to a 2011 congressional report, the toxic chemicals used in fracking include methanol, glutaraldehyde, ethylene glycol, diesel, naphthalene, xylene, hydrochloric acid, toluene and ethylbenzene.[95] More recently, an independent analysis of data submitted by fracking operators to FracFocus revealed that *one-third* of all frack jobs reported there use at least one cancer-causing chemical.[96] These toxic substances can enter drinking water supplies from the well, well pad or in the wastewater disposal process.

Water Used

Since 2005, fracking has used at least 250 billion gallons of water across the nation. Extrapolating from industry-reported figures on water use at more than 36,000 wells since 2011, we estimated total water use for all wells that were fracked from 2005 through mid-2013. (See Table 3.)

The greatest total water consumption occurred in Texas, at the same time the state was struggling with extreme drought. Other states with high water use include Pennsylvania, Arkansas and Colorado. The amount of water used for fracking in Colorado was enough to meet the water needs of nearly 200,000 Denver households for a year.[97]

Table 3. Water Used for Fracking[98]

State	Total Water Used since 2005 (million gallons)
Arkansas	26,000
Colorado	26,000
Kansas	670
Louisiana	12,000
Mississippi	64
Montana	450
New Mexico	1,300
North Dakota	12,000
Ohio	1,400
Oklahoma	10,000
Pennsylvania	30,000
Tennessee	130
Texas	110,000
Utah	590
Virginia	15
West Virginia	17,000
Wyoming	1,200
TOTAL	**250,000**

Air Pollution Created

Fracking created hundreds of thousands of tons of air pollution in 2012. As shown in Table 4, well-site operations during drilling and well completion generated approximately 450,000 tons of health-threatening air pollution. And that does not even include the significant emissions from ongoing operations, compressors, waste pits and truck traffic to and from drilling sites carrying supplies and personnel.

This air pollution estimate for all wells is based on emissions figures from wells in the Marcellus Shale. Different drilling targets and practices may lead to different results.[99] Additional research and improved data availability will help clarify the amount of pollution occurring in different regions.

The 2012 NO_x emissions from the early stages of fracking in Colorado were equal to 27 percent of the NO_x produced by power plants in the state, assuming fracking well emissions rates were similar to those in the Marcellus.[100] In Pennsylvania, fracking produced NO_x equal to 7 percent of that emitted in 2011 by electricity generation, a major source of smog-forming emissions.

Table 4. Estimated Air Pollution Produced from Early Stages of Fracking (Drilling and Well Completion) in 2012 (tons)

State	Particulate Matter	NO_x	Carbon Monoxide	VOCs	Sulphur Dioxide
Arkansas	400	5,300	8,100	700	20
Colorado	1,100	14,000	21,000	2,000	50
Kansas	100	1,700	2,700	200	6
Louisiana	80	1,000	1,600	100	3
Mississippi	Unavailable	Unavailable	Unavailable	Unavailable	Unavailable
Montana	100	1,300	2,000	200	4
New Mexico	300	3,600	5,400	500	10
North Dakota	1,000	13,000	19,000	2,000	40
Ohio	100	1,700	2,600	200	6
Oklahoma	Unavailable	Unavailable	Unavailable	Unavailable	Unavailable
Pennsylvania	800	10,000	15,000	1,000	30
Tennessee	Unavailable	Unavailable	Unavailable	Unavailable	Unavailable
Texas	7,800	100,000	153,000	14,000	300
Utah	400	5,700	9,000	1,000	20
Virginia	1	7	11	1	0
West Virginia	400	4,500	6,900	600	20
Wyoming	270	3,500	5,300	500	12
TOTAL	**13,000**	**170,000**	**250,000**	**23,000**	**600**

Global Warming Pollution Released

Completion of fracking wells produced global warming pollution of 100 million metric tons of carbon dioxide equivalent from 2005 to 2012, equal to emissions from 28 coal-fired power plants in a year.[101]

Using the data on the number of fracking wells, we estimated emissions from well completion using an emissions rate from a recent study by researchers at MIT. The researchers calculated that the average fracked shale gas well completed in 2010 released 110,000 pounds of methane during the first nine days of operation.[102] The researchers assumed that 70 percent of wells were operated with equipment to limit emissions, that 15 percent of wells flared gas, and that 15 percent of wells vented gas. Their calculations did not include methane emissions after the first nine days, such as during processing, transmission and distribution, nor did they include carbon dioxide emissions from trucks and drilling equipment. We used data on the number of wells fracked since 2005 (as presented in Table 1 in "Estimate of Fracking Wells ") to estimate methane emissions. Table 5 presents estimated emissions from completion of fracking wells from 2005 to 2012.

In Texas, emissions from completion of fracking wells since 2005 are equal to those produced by 12 coal-fired power plants in a year.[103] Completion of wells in Pennsylvania produced emissions equal to the pollution from 1.7 million passenger vehicles in a year.[104]

This estimate of emissions from well completion is both incomplete and includes several points of uncertainty. First and foremost, it does not include emissions from ongoing operation of wells. Second, in states where regulators do not have a firm estimate of the number of fracking wells, such as in Colorado and Texas, our conservative estimate of the number of fracking wells results in an underestimate of emissions. Introducing uncertainty, this estimate treats all wells as if they were the same and have the same emissions. In reality, some wells produce gas, some produce oil, and some wells produce gas that requires additional processing.[105] Finally, even those states that track the number of fracking wells typically don't track well type.

We believe this estimate of emissions from well completions understates total emissions from fracking wells. To compare this estimate of emissions from well completion to an estimate from ongoing emissions and to avoid the problem of uncertainty regarding emissions by well type, we estimated emissions based on gas production for a few states.

Table 5. Global Warming Pollution from Completion of Fracking Wells

State	Based on Well Completion from 2005 to 2012 (metric tons of carbon dioxide-equivalent)
Arkansas	6,200,000
Colorado	23,000,000
Kansas	500,000
Louisiana	2,900,000
Mississippi	11,000
Montana	300,000
New Mexico	1,700,000
North Dakota	6,500,000
Ohio	420,000
Oklahoma	3,400,000
Pennsylvania	8,300,000
Tennessee	No estimate
Texas	40,000,000
Utah	1,700,000
Virginia	120,000
West Virginia	4,100,000
Wyoming	1,400,000
TOTAL	**100,000,000**

Researchers at Cornell have studied emissions from fracking in five unconventional gas formations.[106] The researchers estimated the methane emissions released from multiple steps in the fracking process—drilling, fracking and processing—and calculated emissions as a percentage of produced gas.[107] Using estimates of gas production by state, where available, we calculated statewide global warming pollution from fracking. For the two states where we have complete production data—Pennsylvania and North Dakota—the production-based emissions estimate is higher than the estimate based on the number of completed wells.

Using our production-based method, Pennsylvania, North Dakota and Colorado had the highest emissions. Pennsylvania produced the most global warming pollution from fracking for gas. In 2012, the state created 24 million metric tons of carbon dioxide-equivalent, as much pollution as produced by seven coal-fired power plants or 5 million passenger vehicles.[108]

Photo: Gerry Dincher/Flickr.

Storage tanks can be a significant source of fugitive methane emissions.

Acres of Land Damaged

Nationally, land directly damaged for fracking totals 360,000 acres. (See Table 6.) This estimate includes the amount of land that has been cleared for roads, well sites, pipelines and related infrastructure in each state. However, the total amount of habitat and landscape affected by fracking is much greater. In treasured open spaces, a single well-pad can mar a vista seen from miles around. A study of fracking development in Pennsylvania estimated that forest fragmentation affected more than twice as much land as was directly impacted by development.[109]

Fracking activity in Colorado damaged 57,000 acres, equal to one-third of the acreage in the state's park system.[110] In Pennsylvania, the amount of land directly affected by fracking-related development since 2005 is equal to all the farmland protected since 1999 through the state's Growing Greener land preservation program.[111]

Table 6. Land Damaged for Fracking[112]

State	Acres Damaged since 2005
Arkansas	24,000
Colorado	57,000
Kansas	No estimate
Louisiana	No estimate
Mississippi	No estimate
Montana	230
New Mexico	8,900
North Dakota	50,000
Ohio	1,600
Oklahoma	22,000
Pennsylvania	33,000
Tennessee	No estimate
Texas	130,000
Utah	9,000
Virginia	460
West Virginia	16,000
Wyoming	5,000
TOTAL	**360,000**

Photo: ©Dennis Dimick/Flickr.

A grid of drilling sites and roads, similar to those used in fracking, lies across the landscape near Odessa, Texas.

In the years to come, fracking may affect a much bigger share of the landscape. According to a recent analysis by the Natural Resources Defense Council, 70 of the nation's largest oil and gas companies have leases to 141 million acres of land, bigger than the combined areas of California and Florida.[113] Moreover, as noted earlier in this report, the oil and gas industry is seeking access to even more acres of land for fracking—including areas on the doorsteps of our national parks, and inside our national forests—some of which contain sources of drinking water for millions of Americans.

Policy Recommendations

As evidenced by the data in this report, fracking is causing extensive damage to the environment and public health in states across the country. States as disparate as Colorado, North Dakota, Pennsylvania and Texas suffer from air pollution, water pollution, habitat disruption and water depletion caused by widespread fracking. Wherever fracking has occurred, it has left its mark on the environment and our well-being.

Fracking has additional impacts not documented in this report. Environmental damage includes water pollution from spills of fracking fluids and methane leaks into groundwater, as well as air pollution from toxic emissions that causes both acute and chronic health problems for people living near wells. Economic and social damage includes ruined roads and damage to farm economies.

The scale of this threat is growing almost daily, with thousands of new wells being added across the nation each year. Given the scale and severity of fracking's myriad impacts, constructing a regulatory regime sufficient to protect the environment and public health from dirty drilling—much less enforcing such safeguards at more than 80,000 wells, plus processing and waste disposal sites across the country—seems implausible at best.

In states where fracking is already underway, an immediate moratorium is in order. In all other states, **banning fracking is the prudent and necessary course to protect the environment and public health.**

- At a minimum, state officials should allow cities, towns and counties to protect their own citizens through local bans and restrictions on fracking.
- Moreover, states bordering on the fracking boom should also bar the processing of fracking waste so that they will not become dumping grounds for fracking operations next door. Vermont has already banned fracking and its waste, and similar proposals are under consideration in other states.

Where fracking is already happening, the least we should expect from our government is to **reduce the environmental and health impacts of dirty drilling as much as possible**, including:

- The federal government should close the loopholes that exempt fracking from key provisions of our federal environmental laws. For example, fracking wastewater, which often contains cancer-causing and even radioactive material, is exempt from our nation's hazardous waste laws.
- Federal and state governments should protect treasured open spaces and vital drinking water supplies from the risks of fracking. In 2011, the Obama administration's science advisory panel on fracking recommended the "[p]reservation of unique and/or sensitive areas as off limits to drilling and support infrastructure."[114] In keeping with this modest directive, dirty fracking should not be allowed near our national parks, national forests or in watersheds that supply drinking water.

- Policymakers should end worst practices. Fracking operators should no longer be allowed to use open waste pits for holding wastewater. The use of toxic chemicals should not be allowed in fracking fluids. Operators should be required to meet aggressive water use reduction goals and to recycle wastewater.

To ensure that the oil and gas industry—rather than taxpayers, communities or families—pays the costs of fracking damage, states and the Bureau of Land Management should **require robust financial assurance from operators at every well site**.

While we conclude that existing data alone is sufficient to make the case against fracking, additional data will provide a more complete picture and is critical for local communities and residents to assess ongoing damage and liability where fracking is already occurring. As this report revealed, data available on fracking are inconsistent, incomplete and difficult to analyze. To remedy this, oil and gas companies should be required to report all fracking wells drilled, all chemicals used, amount of water used, and volume of wastewater produced and toxic substances therein. Reporting should occur into an accessible, national database, with chemical use data provided 90 days before drilling begins.

Methodology

This report seeks to estimate the cumulative impacts of fracking for oil and gas in the United States. We attempted to limit the scope of the data included in the report to wells using high-volume hydraulic fracturing with horizontal drilling, because that new technology has the greatest environmental impacts and its use is increasing rapidly. However, the definition of and data collection practices for unconventional drilling vary significantly from state to state, making it difficult—and in some cases impossible—to limit our study only to those wells that have been developed using high-volume fracking.

To ensure that our estimates included the most comprehensive data possible, we began by collecting—largely from state oil and gas regulators, as described below—data on all unconventional drilling targets and practices (excluding acidization). Where possible, we then narrowed the data to include only those wells using high-volume hydraulic fracturing involving more than 100,000 gallons of water and/or horizontal drilling. In many states, the information needed to identify these wells was lacking. In those states, we included all wells using unconventional drilling practices in the data. In the section "Number of Wells, Wastewater and Produced Gas," we explain what types of drilling are included in the data for each state.

For data on water use and for teasing apart state data on conventional and unconventional wells, we relied heavily on the work done by SkyTruth to make data reported by the fracking industry more accessible. Oil and gas drilling companies report some of their fracking activities to the FracFocus website, providing information on individual wells in separate PDF files. SkyTruth compiles these individual PDFs and extracts the data "as is," placing the data into a standard machine-readable database that can be downloaded and analyzed. We downloaded SkyTruth's *Fracking Chemical Database* from frack.skytruth.org/fracking-chemical-database/frack-chemical-data-download on 12 June 2013. References below to SkyTruth data or API numbers from SkyTruth refer to this database.

The data we were able to collect undercounts the scope of fracking and its damage, for several reasons. First, when the data were unclear, we made conservative assumptions and chose conservative methodologies. Second, the FracFocus data we drew upon for some of our calculations are incomplete (see text box "Problems with FracFocus Data").

Our analysis does not include data from several states where fracking is a subject of policy debates, including Michigan and California. In those states, the data show that little to no fracking has occurred using high volumes of water because oil and gas companies have not yet begun to combine horizontal drilling with fracking. In these states, hydraulic fracturing has taken place in vertical wells, which require far less water.

Problems with FracFocus Data

Data collected on the FracFocus website have several limitations: FracFocus does not include all fracking wells in the nation, the data that are provided can be of poor quality, and loopholes in reporting requirements enable companies to hide some information.

The FracFocus website does not include data on all fracking wells. The website came into operation in 2011, after thousands of wells had already been fracked and in most cases operators have not retroactively entered information on older wells. Furthermore, in many states, reporting to FracFocus is voluntary and therefore the website does not cover all wells fracked since 2011. Only Colorado, Louisiana, Montana, New Mexico, North Dakota, Oklahoma, Pennsylvania, Texas and Utah require reporting to FracFocus.[115] In most of those states, however, the reporting requirement was adopted in 2012 or later and therefore not all earlier fracking activity is included on FracFocus.

Table 7. FracFocus Contains an Incomplete Count of Fracking Wells (Using More than 100,000 Gallons of Water)

	Count from FracFocus		Count Based on State Data	
State	**Fracking Wells since 2005**	**Fracking Wells in 2012**	**Fracking Wells since 2005**	**Fracking Wells in 2012**
Arkansas	1,461	611	4,910	719
Colorado	4,996	2,308	18,168	1,896
Kansas	150	108	407	236
Louisiana	1,078	346	2,327	139
Mississippi	5	3	9	Unavailable
Montana	264	174	264	174
New Mexico	916	515	1,353	482
North Dakota	2,654	1,653	5,166	1,713
Ohio	156	121	334	234
Oklahoma	2,097	1,270	2,694	Unavailable
Pennsylvania	2,668	1,295	6,651	1,349
Tennessee	2	0	30	Unavailable
Texas	16,916	9,893	33,753	13,540
Utah	1,336	765	1,336	765
Virginia	5	3	95	1
West Virginia	280	170	3,275	610
Wyoming	1,126	468	1,126	468
TOTAL	**36,457**	**19,923**	**81,898**	**22,326**

We compared the data we collected from states with the data included in FracFocus. SkyTruth's database of FracFocus data contains records for approximately 36,000 unique wells that used more than 100,000 gallons of water. Based on data we collected directly from states, we tallied more than 80,000 wells from the beginning of 2005 through mid-2013. Table 7 shows the state-by-state differences between our figures and those derived from FracFocus.

Further evidence of how much data are missing from FracFocus comes from a comparison of water use in all Texas wells reported to FracFocus by individual oil and gas companies versus water use calculated for the Texas Oil & Gas Association. This comparison shows that the figures in FracFocus in 2011 might be 50 percent too low. According to Jean-Philippe Nicot, et al., for the Texas Oil & Gas Association, *Oil & Gas Water Use in Texas: Update to the 2011 Mining Water Use Report*, September 2012, fracking used 81,500 acre-feet of water in Texas in 2011 and consumed 68,400 acre-feet. In contrast, the data from SkyTruth's compilation of FracFocus data suggest total use was 46,500 acre-feet in 2011. Reporting by Texas operators was voluntary at this point, and in 2011 only half of Texas wells were reported to FracFocus, according to Leslie Savage, Chief Geologist, Oil and Gas Division of the Texas Railroad Commission, personal communication, 20 June 2013.

Second, the quality and scope of the data are inconsistent. Typographical errors and incorrect chemical identifying numbers mean some of the data are unusable.

Finally, companies are not required to report all the chemicals they use in the fracking process. Through a trade-secrets exemption, drilling companies can mask the identities of chemicals. In some states, up to 32 percent of the chemicals used are not disclosed because companies claim they are trade secrets, per SkyTruth, *SkyTruth Releases Fracking Chemical Database*, 14 November 2012.

Number of Wells, Wastewater and Produced Gas

We obtained most of our data on a state by state basis for the number of wells, the amount of wastewater produced, and the amount of gas produced.

Arkansas

Data on well completions in Arkansas came from Arkansas Oil and Gas Commission, *Fayetteville Well Completion Report*, downloaded from www.aogc2.state.ar.us/FayettevilleShaleInfo/regularly%20updated%20docs/B-43%20Field%20-%20Well%20Completions.pdf, 4 June 2013. Essentially all these wells are fracked, per James Vinson, Webmaster, Little Rock Office, Arkansas Oil & Gas Commission, personal communication, 4 June 2013. We included wells with no date listed for "Date of 1st Prod" when they had other remarks indicating they were drilled in the past few years.

Our calculation of the volume of flowback and produced water in Arkansas is based on a finding in J.A. Veil, Environmental Science Division, Argonne National Laboratory, for the U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory, *Water Management Practices Used by Fayetteville Shale Gas Producers*, June 2011. Veil reports that one producer in the Fayetteville Shale estimates that "the combined return volume of flowback water and subsequent produced water for the Fayetteville shale is … about 25%." We multiplied this by data on water consumed to frack Fayetteville shale wells in 2012.

Colorado

Colorado does not track fracking wells separately from other oil and gas wells. To estimate the number of fracking wells in the state, we counted the number of wells in Weld, Boulder, Garfield and Mesa counties with spud dates of 2005 or later. Data on well completions came from Colorado Oil and Gas Conservation

Commission, *2013 Production Summary*, accessed at cogcc.state.co.us/, 3 September 2013, and guidance on which counties to include came from Diana Burn, Eastern Colorado Engineering Supervisor, Colorado Oil and Gas Commission, personal communication, 4 September 2013. Many wells in Weld and Boulder counties use fracking to tap the Niobrara and Codell formations, while wells in Garfield and Mesa counties target the Piceance Basin. We excluded wells from all other counties because those wells use lower volumes of water due to shallower wells, foam fracking, or recompletion of existing wells.

Our estimate of gas production and produced water volumes came from Colorado Oil and Gas Conservation Commission, *2012 Annual Production Summary* (Access database), downloaded 25 June 2013. We selected for gas and water production data from all wells drilled in Weld, Garfield, Boulder and Mesa counties since 2005 as described above.

Kansas

We obtained data on all horizontal wells from Kansas Geological Survey, *Oil and Gas Well Database*, accessed at chasm.kgs.ku.edu, 30 May 2013. We counted only those wells with a listed spud date. We were unable to obtain an estimate of wastewater produced.

Louisiana

We obtained data on shale wells drilled in the Haynesville formation from Louisiana Department of Natural Resources, *Haynesville Shale Wells* (spreadsheet), updated 13 June 2013. We counted only those wells with a spud date. The majority of fracking in Louisiana is occurring in the Haynesville shale, per Michael Peikert, Manager, Environmental Section of Engineering Division at the Department of Natural Resource's Office of Conservation, personal communication, early June 2013.

Data on produced water are not available in Louisiana.

Mississippi

Mississippi began requiring permits for fracking wells only in March 2013. Therefore, we used data provided to FracFocus by oil and gas companies involved in fracking. We used the "Find a Well" function on the FracFocus website to search for wells in Mississippi as of 18 June 2013. Reporting to the FracFocus website is voluntary for companies in Mississippi, so the website likely undercounts fracking wells in the state.

Monthly data on produced water are available well by well from the Mississippi Oil and Gas Board's website (http://gis.ogb.state.ms.us/MSOGBOnline/) using individual API numbers. We looked up three wells, one of which has been abandoned, and used the volume of produced water to calculate a state average.

Montana

Our count of fracking wells came from the FracFocus database. We screened for wells that reported using more than 100,000 gallons of water, and counted 264 wells.

This estimate is conservative. A tally of new horizontal and recompleted horizontal wells in Montana Board of Oil and Gas Conservation, *Horizontal Well Completion Count*, accessed at www.bogc.dnrc.mt.gov, 29 May 2013 turned up 1,052 wells, which may include some coalbed methane wells.

To obtain an estimate of produced water, we downloaded the list of API numbers in Montana reported to FracFocus and compiled by SkyTruth. We provided that list of API numbers, which started in 2011, to Jim Halvorson, Petroleum Geologist, Montana Board of Oil and Gas, who queried the state's database for all produced water reports associated with those API numbers in a spreadsheet on 27 June 2013. We summed the produced water figures for the 12-month period ending 31 May 2013.

New Mexico

We calculated the total number of fracking wells in New Mexico in two different ways and chose to use the lower estimate to be conservative.

We counted 1,353 fracking wells by downloading a list of all permitted wells in the state from New Mexico Energy, Minerals and Natural Resources Department, Oil Conservation Division, *OCD Data and Statistics*, 12 June 2013. We selected all wells with an "H" (for hydraulically fractured) at the end of the well name, per a conversation with Phillip Goetze, New Mexico Oil Conservation Division, 25 June 2013. We further screened the wells to include just those with a status of "Active," "Plugged" or "Zone Plugged." We included wells that were identified as "New (Not drilled or compl)" if those records otherwise contained information suggesting the well has been completed (by listing days in production in 2011, 2012, or 2013). This count included a few wells started before 2005.

We counted 1,803 fracking wells by reviewing the list of hydraulic fracturing fluid disclosure forms submitted by drillers for approval before fracking a well. We obtained the list from New Mexico Oil Conservation Division, *Action Status Permitting Database*, 13 June 2013. The requirement to submit these forms began in 2012, so this count doesn't include wells from 2011 and earlier. This approach was based on a conversation with Laurie Hewig, Administrative Bureau Chief, New Mexico Oil Conservation Division, 13 June 2013.

To estimate produced water, we used water production data reported in New Mexico Energy, Minerals and Natural Resources Department, Oil Conservation Division, *OCD Data and Statistics*, 12 June 2013, and filtered as described above. We obtained gas production figures in the same manner.

North Dakota

We obtained data on fracking wells in North Dakota from North Dakota Oil and Gas Division, *Bakken Horizontal Wells by Producing Zone*, accessed at www.dmr.nd.gov, 29 May 2013. We assumed that all horizontal wells are fracked and that all fracking in the state happens in the Bakken Shale. We obtained data on produced water from this same data source. However, reported production data are cumulative by well and we could not calculate production by all fracking wells over a one-year period. Therefore, our tally of water includes multiple years of production.

Data on gas production from fracking wells comes from North Dakota Industrial Commission, Department of Mineral Resources, *North Dakota Monthly Gas Production and Sales*, accessed at www.dmr.nd.gov/oilgas/stats/Gas1990ToPresent.pdf, 9 August 2013. We tallied production in 2012 only.

Ohio

For Ohio, we included data for wells drilled in both the Marcellus and Utica shales from the Ohio Department of Natural Resources, Division of Oil & Gas Resources. The state separates shale well permit activity into Marcellus and Utica categories, and presents it in spreadsheets entitled *Cumulative Permitting Activity*, available at oilandgas.ohiodnr.gov/shale#SHALE, with well sites permitted through 2 May 2013.

Produced water and gas information for the Utica came from Ohio Department of Natural Resources, Division of Oil & Gas Resources, *2012 Utica Shale Production Report*, 16 May 2013. Data on production from the 11 drilled Marcellus wells came from Ohio Department of Natural Resources, Division of Oil & Gas Resources, *Ohio Oil & Gas Well Database*, accessed at http://oilandgas.ohiodnr.gov/well-information/oil-gas-well-database, 24 June 2013. We used the API numbers from Ohio Department of Natural Resources, Division of Oil & Gas Resources, *Marcellus Shale Horizontal Wells*, 6 July 2013.

Oklahoma

Our count of fracking wells in Oklahoma came from a database downloaded from FracTracker, *Oklahoma Shale Wells (3-18-2013)*, accessed at www.fractracker.org/downloads/, 28 June 2013. The database does not contain any date information.

Pennsylvania

We included data for all unconventional wells with spud dates of January 1, 2005 and later from Pennsylvania Department of Environmental Protection, *Oil and Gas Reports: SPUD Data Report*, www.portal.state.pa.us, 29 May 2013.

Data on gas and water produced in 2012 from Pennsylvania's fracking wells came from the Pennsylvania Department of Environmental Protection, *PA DEP Oil & Gas Reporting Website—Statewide Data Downloads by Reporting Period*, accessed at www.paoilandgasreporting.state.pa.us/publicreports/Modules/DataExports/DataExports.aspx, 24 June 2013. Our produced water tally included "Drilling Fluid Waste," "Fracing Fluid Waste" and "Produced Fluid."

Tennessee

Our estimate of the number of fracking wells came from Ron Clendening, Geologist, Oil & Gas Contacts, Division of Geology, Tennessee Department of the Environment and Conservation, personal communication, 8 July 2013. We were unable to obtain an estimate of wastewater or gas production.

Texas

Texas began keeping track of fracking wells in February 2012. To compile an estimate of fracking wells since 2005, we used several data sources.

- 2005-2009: We assume that from 2005 through 2009, the bulk of fracking activity in Texas occurred in the Barnett Shale and was barely beginning elsewhere. A total of 8,746 new horizontal wells were drilled in the Barnett Shale from 2005 through 2009, per *Powell Barnett Shale Newsletter*, 18 April 2010, as cited in Zhongmin Wang and Alan Krupnick, *A Retrospective Review of Shale Gas Development in the United States*, Resources for the Future, 2013. The Eagle Ford Shale was first drilled in 2008 and by 2009 there were 107 producing oil and gas wells, per Texas Railroad Commission, *Eagle Ford Information*, accessed at www.rrc.state.tx.us/eagleford/, 3 September 2013.
- 2010: Nearly 40 percent of wells drilled in 2010 were fracked using more than 100,000 gallons of water, per Table 7 of Jean-Philippe Nicot, et al., Bureau of Economic Geology, Jackson School of Geosciences, University of Texas at Austin, for the Texas Water Development Board, *Current and Projected Water Use in the Texas Mining and Oil and Gas Industry*, June 2011. We multiplied 39.7 percent times the 8,133 "new drill dry/completions" in 2010, per Railroad Commission of Texas, *Summary of Drilling, Completion and Plugging Reports,* accessed at www.rrc.state.tx.us/data/drilling/drillingsummary/index.php, 19 July 2013.
- January 2011 through January 2012: We calculated the number of fracking wells in this period by multiplying the number of wells drilled by an estimate of the percentage of those wells that were fracked. The number of "new drill dry/completions" came from Railroad Commission of Texas, *Summary of Drilling, Completion and Plugging Reports,* accessed at www.rrc.state.tx.us/data/drilling/drillingsummary/index.php, 3 September 2013. We interpolated between 2010 and February 2012 using the percentage of wells that were fracked using the 2010 estimate of 39.7 percent, described above, and the percent fracked from February 2012 to April 2013, described below.
- February 2012 through April 2013: Beginning in February 2012, drilling companies in Texas have been required to report their drilling activities

to FracFocus. Per SkyTruth, 19,678 wells were fracked in Texas in that period that used more than 100,000 gallons of water. This number of wells equals 82.5 percent of all "new drill dry/completions" in the same period in Railroad Commission of Texas, *Summary of Drilling, Completion and Plugging Reports,* accessed at www.rrc.state.tx.us/data/drilling/drillingsummary/index.php, 3 September 2013.

Texas does not require reporting of produced water volumes. However, the state does track the volume of water that is injected into disposal wells or for enhanced recovery in other wells. Our estimate of wastewater is based on the assumption that 99 percent of all produced water is reinjected, and therefore reinjected water volumes indicate wastewater production, per Leslie Savage, P.G., Chief Geologist, Oil & Gas Division, Railroad Commission of Texas, personal communication, 18 July 2013. Ms. Savage queried the Railroad Commission's *H10 Filing System* to return results on injected saltwater volumes in 2012, which we used as the basis of our estimate. This includes both flowback and produced water.

Utah

Our count of fracking wells came from the FracFocus database. We screened for wells that reported using more than 100,000 gallons of water, and counted 1,336 wells.

We calculated gas and produced water volumes from fracking wells in Utah from Utah Department of Natural Resources, Division of Oil, Gas and Mining, *Production Data*, accessed at http://oilgas.ogm.utah.gov/Data_Center/DataCenter.cfm#download, 12 July 2013. To limit our tally to production from fracking wells, we used API numbers for all Utah wells included in SkyTruth's database from FracFocus data. Of the 1,607 wells with APIs in SkyTruth's database, we found 2012 production reports for 1,364 wells in Utah's data.

Virginia

We counted all horizontal wells included in Virginia Department of Mines, Minerals, and Energy Division of Gas and Oil Information System, *Drilling Report*, accessed at www.dmme.virginia.gov, 29 May 2013.

We were unable to obtain data on produced water. An estimated 15 to 30 percent of water and chemicals used to frack a well returns to the surface, per Virginia Department of Mines, Minerals, and Energy, Division of Gas and Oil, *Hydraulic Fracturing in Virginia and the Marcellus Shale Formation*, accessed at www.dmme.virginia.gov/DGO/HydraulicFracturing.shtml, 12 July 2013. However, we were unable to obtain data on how much formation water also is produced.

West Virginia

Our data for West Virginia includes all permitted wells targeting the Marcellus Shale. We were unable to narrow our count to drilled wells. We also chose to include wells without a listed permit date, on the assumption that any Marcellus drilling in West Virginia has occurred recently. Data is from West Virginia Department of Environmental Protection, *Resource Extraction Data Viewer*, http://tagis.dep.wv.gov/fogm/, 20 June 2013.

We tallied gas production from 2011 (the most recent year reported). We obtained 2011 production data from West Virginia Department of Environmental Protection, *Oil and Gas Production Data*, accessed from www.dep.wv.gov/oil-and-gas/databaseinfo/Pages/default.aspx, 12 July 2013. We looked up production from fracking wells by using the API numbers reported to FracFocus and compiled in SkyTruth's database. Our calculation of production is an underestimate because only 52 wells from FracFocus corresponded to wells in West Virginia's production database.

West Virginia does not collect water production data.

Wyoming

We used data on fracking wells reported to the FracFocus database to ensure we did not accidentally include coalbed methane wells. There are 1,126 wells in the FracFocus database that report using more than 100,000 gallons of water.

This figure from FracFocus is close to data we obtained through another approach. We tallied 1,273 horizontal wells since 2005 in Wyoming from FracTracker, *WY_horiz_06032013*, accessed at www.fractracker.org/data/, 28 June 2013. FracTracker obtained this list via a request to the Wyoming Oil and Gas Conservation Commission. This estimate excludes any wells that list a spud date before 2005, and includes wells with no date or that were flagged as coalbed.

Water Used

We multiplied the number of fracking wells per state since 2005 by average water use per well per state since 2011.

Average water use per well that reported using more than 100,000 gallons came from Skytruth, *Fracking Chemical Database*, accessed at http://frack.skytruth.org/fracking-chemical-database/frack-chemical-data-download, 12 June 2013. SkyTruth compiled data posted in PDFs on the FracFocus website into a database that includes water use, which can encompass freshwater, produced water and/or recycled water. The inclusion of recycled water may lead to some double-counting of water used. We included data beginning in 2011 through the most recent entries for 2013. In calculating average water consumption per well, we excluded wells that listed "None" for water use. We excluded what appeared to be duplicate entries, based on API numbers, frack date and reported water use. We also excluded two wells from Texas that reported using more than 1 billion gallons of water each, which we assumed was a data entry error by the reporting operator.

To estimate water use since 2005, we multiplied average water use per reporting well in each state by the number of fracking wells (using more than 100,000 gallons of water) in each state since 2005. The source of our well count is described in the previous section.

Air Pollution

We used data from New York State's assessment of air pollution from each well site to estimate the volume of particulate matter, smog precursors and other hazardous compounds from fracking. Though the U.S. Environmental Protection Agency recently studied air pollution from gas drilling, the data were compiled primarily from vertically rather than horizontally fracked wells and were limited to fewer types of pollutants (see EC/R, Inc., for U.S. Environmental Protection Agency, *Oil and Natural Gas Sector: Standards of Performance for Crude Oil and Natural Gas Production, Transmission, and Distribution. Background Technical Support Document for Proposed Standards*, July 2011. New York State's pollution assessment was more complete and more relevant to high-volume fracking wells.

We assume that four wells per drilling site are drilled, fracked and completed each year, per New York State Department of Environmental Conservation, *Revised Draft Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program: Well Permit Issuance for Horizontal Drilling And High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs*, 7 September 2011, 6-105. We assumed that wells produce dry gas, not wet gas, and that operators flare flowback gas instead of simply venting it. This first assumptions means our air pollution estimate may understate the problem, since wet gas wells have higher emissions, while our second assumption changes the mix of pollutants released. We multiplied the tons-per-year emissions estimates from Table 6.7 of the *Revised Draft Supplemental Generic Environmental Impact Statement* by a recent year's well completion figure for each state.

This emissions estimate does not include the significant emissions from ongoing operations, compressors, and truck traffic to and from drilling sites carrying supplies and personnel.

Methane Emissions

We calculated methane emissions using two different approaches because neither approach alone provided a complete picture. The lack of data on wells drilled, gas produced and emissions per well makes it very hard to assess the extent of global warming damage from fracking. Our first approach multiplied emissions per well during completion by the number of fracking wells. Our second method multiplied emissions as a percentage of gas produced by the amount of gas produced from fracking wells.

In states with more comprehensive production data, the energy-based calculation may be more accurate because it is based on state-specific conditions. In addition, the energy-based method includes emissions from a wider range of activities involved in producing gas from fracking wells—from drilling to fracking to processing—and therefore better reflects the impact of fracking.

In states where we could obtain no or limited emissions data, the estimate based on per-well emissions during completion offers a rough emissions estimate. The per-well emission factor is conservative because it is based on a narrower definition of fracking activity (it excludes production and processing). However, it may overestimate emissions from wells that were drilled but produced little to no gas.

Emissions Based on Well Completion

We estimated methane emissions by multiplying an estimate of emissions per completion of a fracking gas well by the number of fracking wells in 2012 in each state. We estimated average emissions of 50,000 kilograms of methane per well, per Francis O'Sullivan and Sergey Paltsev, "Shale Gas Production: Potential Versus Actual Greenhouse Gas Emissions," *Environmental Research Letters*, 7:1-6, 26 November 2012, doi: 10.1088/1748-9326/7/4/044030. This estimate is a national average based on nearly 4,000 wells completed in 2010 and assumes 70 percent of wells undergo "green" completions in which fugitive emissions are captured. This likely overstates the green completions rate before 2010.

Our estimate has two limitations of note. First, it does not include methane emissions from pipelines, compressor stations, and condensate tanks, or carbon dioxide emissions from equipment used to produce gas. Second, it may not accurately reflect emissions from fracked shale wells that produce oil rather than gas. The data we obtained on well completions do not distinguish between wells fracked for oil versus gas production and therefore we have chosen to apply this estimate for shale gas wells to all wells. We spoke with two experts in the field who believe that, given the lack of better data on emissions from oil wells, is it reasonable to assume that fracked oil wells have substantial methane emissions.

We converted methane emissions to carbon dioxide equivalents using a 100-year global warming potential of 25 times that of carbon dioxide, per Federal Register, *Environmental Protection Agency, 40 CFR Part 98, 2013 Revisions to the Greenhouse Gas Reporting Rule and Proposed Confidentiality Determinations for New or Substantially Revised Data Elements; Proposed Rule*, 78(63): 19802-19877, 2 April 2013.

Emissions Based on Gas Production

We calculated methane emissions as a percentage of gas production. See the previous section for a description of how we estimated gas production in each state.

We converted cubic feet of gas production to megajoules of methane using the assumption that 78.8 percent of gas produced from unconventional wells is methane, per Robert Howarth, et al., "Methane and the Greenhouse Gas Footprint of Natural Gas from Shale Formations," *Climatic Change* 106: 679-690, 2011. (Note that other researchers have estimated the methane content of Marcellus Shale gas as high as 97.2 percent. See ICF International, Technical Assistance for New York State Department of Environmental Conservation, *Draft Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program*, as cited in Mohan Jiang, et al., "Life Cycle Greenhouse Gas Emissions of Marcellus Shale Gas," *Environmental Research Letters,* 6, 034014, July-September 2011, doi:10.1088/1748-9326/6/3/034014, supplemental materials.)

We assume that 3.3 percent of the methane produced over the life of a well is lost as fugitive emissions, per Robert Howarth, et al., "Methane and the Greenhouse Gas Footprint of Natural Gas from Shale Formations," *Climatic Change* 106: 679-690, 2011, as presented in Robert Howarth, et al., *Methane Emissions from Natural Gas Systems; Background Paper Prepared for National Climate Assessment,* 25 February 2012. This estimate includes well-site and processing emissions from shale and tight-gas sands wells that produce gas. The estimate assumes significant venting of methane in the initial days after a well is fracked.

The 3.3 percent pollution rate from Howarth, et al., is higher than reported in EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 to 2011*, 12 April 2013. However, it is in the range of one recent study that measured fugitive emissions over a gas and oil field in Colorado, finding fugitive methane emissions of 2.3 to 7.7 percent of gas produced (Gabrielle Pétron, et al., "Hydrocarbon Emissions Characterization in the Colorado Front Range: A Pilot Study," *Journal of Geophysical Research*, 117, D04304, 2012, doi:10.1029/2011JD016360, and Jeff Tollefson, "Air Sampling Reveals High Emissions from Gas Field," *Nature*, 483(7384): 139-140, 9 February 2012, doi: 10.1038/482139a). A second recent study in the same area measured methane emissions equal to 6.2 to 11.7 percent of production (Anna Karion, et al., "Methane Emissions Estimate from Airborne Measurements over a Western United States Natural Gas Field," *Geophysical Research Letters*, 27 August 2013, doi: 10.1002/grl.50811).

We used a slightly different method to calculate emissions for North Dakota, where a large portion of gas is flared rather than sold. We calculated emissions for the flared gas and emissions for the remaining gas separately. Because of lack of infrastructure to get gas to market, 29 percent of all gas produced in North Dakota is flared, per Lynn Helms, North Dakota Industrial Commission, Department of Mineral Resources, *Director's Cut*, 15 July 2013. We estimated emissions from this gas based on New York State Department of Environmental Conservation, *Revised Draft Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program: Well Permit Issuance for Horizontal Drilling And High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs*, 7 September 2011, 6-194. We calculated emissions from the remaining wells using Robert Howarth, et al., "Methane and the Greenhouse Gas Footprint of Natural Gas from Shale Formations," *Climatic Change* 106: 679-690, 2011, as presented in Robert Howarth, et al., *Methane Emissions from Natural Gas Systems; Background Paper Prepared for National Climate Assessment*, 25 February 2012.

Landscape Impacts

We calculated landscape impacts based on the number of wells in each state. We divided the number of wells drilled (or permitted, if only that figure was available) since the beginning of 2005 by the average number of wells per pad to obtain the number of well pads. We then multiplied the number of well pads by the size of each well pad and the roads and pipelines servicing it. Where possible, we used state-specific estimates about the number of wells per pad and the acreage damaged by pads and supporting infrastructure.

For states where most drilling is into the Marcellus Shale (**Pennsylvania** and **West Virginia**), we assumed that land disruption patterns are comparable to those in Pennsylvania, where existing drilling practices place an average of 1.8 wells per well pad. Well pads average 3.1 acres and associated infrastructure disturbs 5.7 acres. Pennsylvania data were presented in New York State Department of Environmental Conservation, *Revised Draft Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program: Well Permit Issuance for Horizontal Drilling And High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs*, 7 September 2011, 6-76. We assumed **Ohio** and **Virginia** follow the same land disturbance patterns.

In **Oklahoma**, we assumed 1.1 wells per pad, and the same wellpad size and road and pipeline impacts as in Ohio and Pennsylvania.

For **Texas**, we assumed two wells per pad because the sources we consulted suggest that there are some multi-well pads but that the number of wells per pad remains small. In the Barnett, well pads hold anywhere from one to eight wells, per George King, GEK Engineering, *Multi-Well Pad Operations for Shale Gas Development, Draft Document*, 5 May 2010. In the Eagle Ford Shale, Chesapeake Energy, as of early 2013, was drilling only half of its wells on multi-well pads, per Jennifer Hiller, "Chesapeake Thinks It Has 342 Million Barrels in Eagle Ford," *Eagle Ford Fix* (blog operated by *San Antonio Express-News*), 6 May 2013. We assumed pad size is the same as in Pennsylvania (which has an average of 1.8 wells per pad). We assume road and pipeline infrastructure occupies 4.75 acres, the same as on public land in western Colorado.

For **New Mexico**, we estimated the number of wells per pad after mapping the location of fracking wells reported to FracFocus in 2012. We used the API number of those wells to obtain the latitude and longitude for each well from New Mexico Energy, Minerals and Natural Resources Department, Oil Conservation Division, *OCD Data and Statistics*, 12 June 2013. A small number of 2012 wells appear to be on multi-well pads. Given that in neighboring Texas, few wells before 2012 were drilled on multi-well pads, we assumed that New Mexico wells average 1.1 wells per pad. We assumed pad size for a single-well pad is 2.47 acres, based on the average pad size and wells per pad in Weld County, Colorado (see below). We assumed road and pipeline infrastructure occupies 4.75 acres, the same as on public land in western Colorado.

We made the same assumption for **Utah**, based on mapping the location of fracking wells and finding few multi-well pads.

For **Colorado**, we obtained estimates for acres damaged by wells in Weld County and on public land in western Colorado. By looking at the Form 2A documentation for 20 fracking wells across Weld County, we found that an average of 2.25 wells are drilled per pad and that well pads disturb an average of 5.56 acres. We could not obtain an estimate of land disturbed for roads and pipelines. We obtained this data from Colorado Oil and Gas Conservation Commission, *GISOnline*, accessed at http://dnrwebmapgdev.state.co.us/mg2012app/, 11 July 2013. Leases on federal land in western Colorado average eight wells per pad, with 7.25 acres of land disturbed per pad and an additional 4.75 acres for roads and other infrastructure, per U.S. Department of the Interior, Bureau of Land Management, Colorado State Office, Northwest Colorado Office, White River Field Office, *Draft Resource Management Plan Amendment and Environmental Impact Statement for Oil and Gas Development*, August 2012. For our calculation, we used the Weld County data for Weld and Boulder wells, and the western Colorado estimates for Garfield and Mesa wells. We used the western Colorado estimate of acreage for supporting infrastructure.

For **Wyoming**, we assumed an average of two wells per pad. Drilling in the Jonah Field is estimated to occur with single well pads and in the Pinedale Anticline with multiple wells per pad, per U.S. Department of the Interior, Bureau of Land Management, Pinedale Field Office, *Proposed Resource Management Plan and Final Environmental Impact Statement for Public Lands Administered by the Bureau of Land Management, Pinedale Field Office*, August 2008. From that same source, we used an estimate of four acres per two-well pad, and 4.9 acres for roads and pipelines per pad.

In **Montana**, we calculated land impacts based on data from current land impacts of wells in the HiLine Planning Area in north central Montana. Existing wells in the Bowdoin Dome and the rest of the HiLine Planning Area (which may not be high-volume wells) disturb an average of 0.21 acres per well pad and 0.67 acres for roads and flow lines, based on a weighted average of data presented in Table 22 of Dean Stillwell and J. David Chase, U.S. Department of the Interior, Bureau of Land Management, *Reasonable Foreseeable Development Scenario for Oil and Gas Activities on BLM-Managed Lands in the HiLine Planning Area, Montana, Final Report*, 30 October 2012. We assumed one well per pad.

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99. Emissions of hazardous air pollutants will be higher in regions with wet gas that requires additional processing. The mix of pollutants will be different in regions that use more venting than flaring, see note 46, 6-105. Also, data from a study conducted by a professor at Southern Methodist University on air pollution from fracking operations in the Barnett Shale area of Texas suggest that emissions from oil wells are lower than from gas wells because of differences in emissions from storage tanks. See note 43.

100. Power plant emission data are from 2011: U.S. Energy Information Administration, *U.S. Electric Power Industry Estimated Emissions by State, back to 1990 (EIA-767 and EIA-906)*, February 2013.

101. Calculated using U.S. Environmental Protection Agency, *Greenhouse Gas Equivalencies Calculator*, accessed at www.epa.gov/cleanenergy/energy-resources/calculator.html, 9 September 2013.

102. Francis O'Sullivan and Sergey Paltsev, "Shale Gas Production: Potential Versus Actual Greenhouse Gas Emissions," *Environmental Research Letters*, 7:1-6, 26 November 2012, doi: 10.1088/1748-9326/7/4/044030.

103. See note 101.

104. Ibid.

105. We spoke with two experts in the field who believe that, given the lack of better data on emissions from oil wells, is it reasonable to assume that fracked oil wells have substantial methane emissions.

106. Robert Howarth, et al., "Methane and the Greenhouse Gas Footprint of Natural Gas from Shale Formations," *Climatic Change* 106: 679-690, 2011.

107. As presented in Robert Howarth, et al., *Methane Emissions from Natural Gas Systems; Background Paper Prepared for National Climate Assessment,* 25 February 2012.

108. See note 101.

109. See note 53.

110. Colorado Parks & Wildlife, *2013 Factsheet: A Review of Statewide Recreation and Conservation Programs*, accessed at http://wildlife.state.co.us/SiteCollectionDocuments/DOW/About/Reports/StatewideFactSheet.pdf, 16 July 2013.

111. Growing Greener Coalition, *Growing Greener Environmental Stewardship Fund*, accessed at http://pagrowinggreener.org/issues/growing-greener/, 16 July 2013.

112. See methodology for explanation of how this was calculated.

113. Natural Resources Defense Council, *Spreading Like Wildfire: Oil and Gas Leases Mean that Fracking Could Occur on Tens of Millions of Acres of U.S. Lands*, February 2013.

114. U.S. Department of Energy, The Secretary of Energy Advisory Board, Shale Gas Production Subcommittee, *Second Ninety-Day Report*, 18 November 2011.

115. Vinson & Elkins LLP, *Hydraulic Fracturing Fluid Disclosure Requirements*, 26 October 2012.

Exhibit 12

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Be careful of what you wish for

The economic impacts of Queensland's unconventional gas experiment and the implications for Northern Territory policy makers.

Discussion paper

Mark Ogge
November 2015

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Summary

The gas industry says that unconventional gas development brought an economic and jobs boom to Queensland, and promises the same for the Northern Territory. Territorians should test the claims of the industry in Queensland to determine the likely economic and jobs impacts of unconventional gas development in the Northern Territory.

In contrast to the economic benefits promised , recent gas industry funded studies of the economic and social impacts of gas in Queensland's unconventional gas fields have found:

- Local business stakeholders reported a deterioration in:
  - Financial capital
  - Local Infrastructure
  - Local skills
  - Social cohesion
  - The local environment
- Unconventional gas has affected community wellbeing:
  - Fewer than one in four local people approved of the unconventional gas industry, with less than 6% believing it would "lead to something better".
- Unconventional gas creates few additional jobs:
  - There were virtually no spillover jobs created in local retail or manufacturing.
  - Gas jobs will be slashed by 80% at the end of the construction period.
- For every 10 unconventional gas jobs created, 7 service sector jobs were lost.

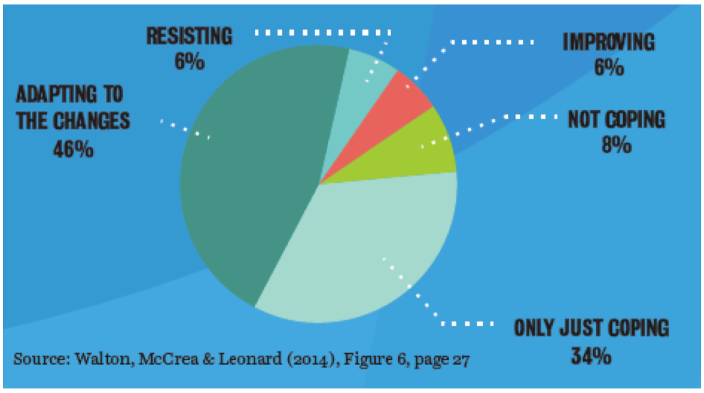
Figure 1: The impact of unconventional gas development on local businesses.

How did local business stakeholders in Queensland's Darling Downs perceive the impact of unconventional gas and mining on their region?

Source: CSRM University of Queensland

Financial capital	Worse
Infrastructure	Worse
Labour force skills	Worse
Social networks	Worse
Environment	Worse

Figure 2: The social impacts of unconventional gas development on communities in Queensland's Darling Downs



There have also been few economic benefits for the wider economy. The industry emphasises the high *value* of the gas it exports, but the value of gas exports largely flow to the gas companies thather than to the Australian community. As the Reserve Bank of Australia concluded:

> The effect on Australian living standards will be less noticeable than [the increase in gas production] given the low employment intensity of LNG production, the high level of foreign ownership of the LNG industry and, in the near term, the use of deductions on taxation payments.[1]

Queensland's experience shows that reality does not match the unconventional gas industry's claims. Few benefits are realised outside the gas industry, and there are serious social and economic effects on local communities and existing businesses.

[1] Cassidy N and Kosev M, (2015) Australia and the Global LNG Market, RBA

[2] Thae Austraila Institute facts Fight Back June 30 2013. http://www.factsfightback.org.au/did-the-gas-industry-create-100000-jobs-last-year-check-the-facts/

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Introduction

When seeking development approval, oil and gas companies justify their projects' significant environmental and social harm on the grounds that the projects will bring jobs and economic growth.

The huge profits at stake encourage companies to exaggerate the economic benefits of their projects and downplay their negative effects. These economic claims are made in formal approval process, public relations activities and lobbying of policy makers.

This kind of exaggeration has become routine for many resource companies, often reaching almost comic proportions. Notorious cases include the Rio Tinto Warkworth coal mine expansion in NSW where the company claimed it would create 44,000 additional jobs despite the expansion only requiring 130 additional workers. The NSW Land and Environment Court rejected the companies claims and overturned the approval, a decision that was upheld by the Supreme Cort of NSW. Similarly the proponants of the proposed the Carmichael coal mine the project would create 10,000 jobs. When challenged in court the companies own economic expert acknowledgers actual figure was less than 1,476 jobs.

In 2013 the Australian Petroleum Production and Exploration Association APPEA claimed that the oil and gas industry had created a 100,000 new jobs in a single year. According to The Australian Bureau of Statistics the oil and gas industry in Australia added only 9,400 jobs that year, and employed 20,700 people in total.[2] Even countinag all the addition construction jobs would come nowhere near the 100,000 jobs claimed. These additional construction jobs woud have come largely at the expense of jobs in other industries, patricuarly given the very tight labour market at the time.

The absurdity of the claims belies the seriousness of the deception.

These projects have serious environmental and social impacts that are too often ignored by policy makers and bureaucrats who have been willing to accept the assurances of resource companies with little scrutiny applied to their claims. This has sometimes led to serious environment and social impacts for local communities from projects that provide little benefit to the wider population.

[2] Thae Austraila Institute facts Fight Back June 30 2013. http://www.factsfightback.org.au/did-the-gas-industry-create-100000-jobs-last-year-check-the-facts/

The huge unconventional gas projects approved in Queensland in 2010 are a case in point. The economic claims of the proponants were not tested by the government, despite its obligation to objectively assess the projects. Recent research examined in this paper clearly shows that few of the promised benefits have materialised and existing businesses and entire industries have been badly affected. Long-term jobs have been sacrificed for short-term gas construction jobs.

Only 6% of local people living in gasfield areas think that the industry has improved their lives – as many as are actively resisting it. As well as active resisters, a further 42% say that they are “not coping” or “only just coping” with the changes the industry has made to their lives. Actual royalty payments are a small fraction of the estimates made at approval and flow on economic activity failed to materialse, as companies bypassed local industry and suppliers in favour of global supply chains.

The Northern Territory government has issued unconventional gas licenses for almost the entire territory. Speculative gas interests have a strong incentive to increase the value of their licenses by gaining environmental approvals and government promises to subsidise infrastructure.

Northern Territory policy makers can learn from the experience in Queensland. The economic claims of the unconventional gas industry must be subject to scrutiny and due diligence. Projects should only proceed if they provide a net benefit to the Territory community, not just quick profits for gas companies.

1. The impacts of unconventional gas developments on local businesses

While some people and businesses benefit from unconventional gas development, many other businesses and industries can be negatively impacted and jobs in other sectors are often lost as a result.

The most advanced unconventional gas development in Australia is in Queensland's Darling Downs. The gas industry uses this region as an example of the economic benefits that unconventional gas provides local communities[3]. The research tells a more complicated story.

The most detailed examination of the economic impacts of unconventional gas development in the Darling Downs is a study carried out between 2008 and 2013 by the industry-funded Sustainable Minerals Institute SMI at the University of Queensland. [4]

This study surveyed stakeholders from different sectors in the local community including the local business community, agriculture, local government, advocacy groups and environmental consultants, as well as the mining and unconventional gas industries.

The survey asked stakeholders to assess the effect of unconventional gas and mining in the region over a five-year period on the following key indicators:

1. **Financial capital:** Available revenue streams and economic resources.
2. **Built capital:** The physical infrastructure such as buildings, transport, equipment.
3. **Social capital:** The degree to which people know each other and collaborate and the level of trust people have in local organisations and institutions.
4. **Human capital:** Assets such as skills, knowledge, abilities and good health possessed by individuals that enable them to work, earn a living, contribute to society and thereby build other forms of capital.
5. **Natural capital**: Key natural resources, such as water, land, clean air, wildlife and forests that people can access for lifestyle or livelihood purposes.

[3] Natural Coal Seam Gas, Regional Development, APPEA http://www.naturalcsg.com.au/benefits/regional-development/

[4] Everingham, J., Collins, N., Rodriguez, D. Cavaye, J., Vink, S., Rifkin, W. & Baumgartl, T. (2013) *Energy resources from the food bowl: an uneasy co-existence. Identifying and managing cumulative impacts of mining and agriculture. Project report*. CSRM, The University of Queensland: Brisbane.

All stakeholder groups other than those representing mining and unconventional gas believed that the development of mining and unconventional gas had a negative impact on all or most types of capital. Even the mining and unconventional gas industries thought that local infrastructure had deteriorated as a result of mining and unconventional gas development in the region.

Figure 3: Stakeholder responses assessing the change in different types of capital over the last 5 years as a result of interaction between gas and other industries.

	Financial capital	Human capital	Built capital	Social capital	Natural capital
Gas	Better	Better	Worse	Better	Better
Mining	Better	Better	Worse	Better	Better
Agriculture	Worse	Worse	Worse	Worse	Worse
Local business	Worse	Worse	Worse	Worse	Worse
Local government	Worse	Better	Worse	Same	Same
Community	Worse	Better	Worse	Worse	Worse
Advocacy	Worse	Worse	Worse	Worse	Worse

Far from mining and unconventional gas providing economic benefits, local businesses felt that it had reduced financial capital, human capital, infrastructure, social capital and natural capital.

Local businesses have to compete with inflated gas industry wages if they want to recruit and retain staff and they experience increased rent and competition for services (particularly trade and mechanical repairs). There are also disruptions to farmers from the rollout of access roads, pipelines, water treatement plants and other infrastructure. Big increases in truck traffic tend to disrupt other forms of transport and damage roads.

Some businesses do benefit. Motels, bars and fast food chains experience a burst of demand during the brief construction phase, but may struggle afterwards. Waste disposal companies can profit from storing, transporting and treating the millions of litres of toxic “produced” or “flow-back” water and salt from the extraction process.

Some stakeholders discussed the effect on existing local businesses:

> Obviously if you've got a major engineering or earth moving business, you attract business, you're doing incredibly well, or a motel.
>
> But, if you work in town at a local shop, or the council, you're doing incredibly poorly, because your rents have gone through the roof and suddenly you're flat out paying to be able to live in town. For us, we're seeing increased costs.
>
> All our professional services are $100 an hour plus, whereas they used to be [in the] 40s and 50s. Freight is dearer. We can't get labour. We're relying on backpackers a lot more because we just can't get permanent staff. So, it's quite an added cost to one sector of the community, while the other sector booms. [5]

Having to compete with inflated resource industry wages was also of great concern:

> What they're paying for wages [in some towns] is two and half times what the wage should be – just to hold men. That's forcing consumer goods up, to try to cover the costs of those wages… So it's all spinning down the line… [For example] from a hardware perspective, anyone doing renovations to their home, even just the little bits are all getting more expensive because these guys are trying to cover the increase in wages that they've had to pay to retain men. And the [resources] companies are walking into businesses and offering staff – mainly mechanics… huge wages. 6

Other stakeholders described the corrosion of social capital:

> [I]n regards to a divide between people, not just landholders versus townies, but for instance I've got a lot of friends who used to work in agriculture and now work for gas companies – a lot of them. And some family members don't speak to them anymore because they're still on the land...
>
> But even in towns now… once you would go to the local pub in Dalby, it was all full of farmers and that sort of thing and now you've got guys in their high vis' and after a few rums things are getting… they do, it's starting to get quite ugly. There's quite a bit of animosity going on. And agricultural communities have never been like that – they're not. And now that's building up pretty much. [7]

It is clear from interviews with businesses in unconventional gas development areas that the industry brings substantial costs. The CSRM study showed that business

[5] Everingham et al, p 38.
[6] Everingham et al, p 39.
[7] Everingham et al, p 51.

stakeholders perceived the costs as outweighing the benefits. Territory business organisations and policy makers should be aware of how this has played out in Queensland when considering the expansion of the gas industry in the NT.

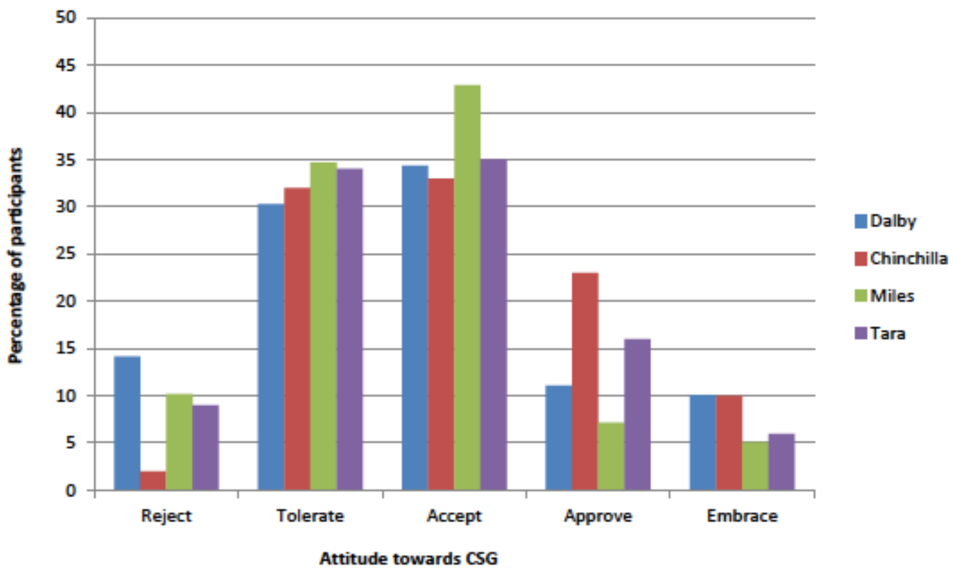
Negative impacts on local businesses also affect communities at the social level. The next section examines the social impacts in more detail.

2. Impacts on local communities

Unconventional gas development in Queensland's Darling Downs distresses local communities. Few people approve of the industry and even fewer believe it will improve conditions.

A recent CSIRO survey of the Western Darling Downs found that almost half the local population was "only just coping" with, "not coping" with or actively resisting the changes to their communities caused by unconventional gas development. This study was undertaken by researchers funded by the largest unconventional gas companies in Queensland, including Australia Pacific LNG and QGC.[8]

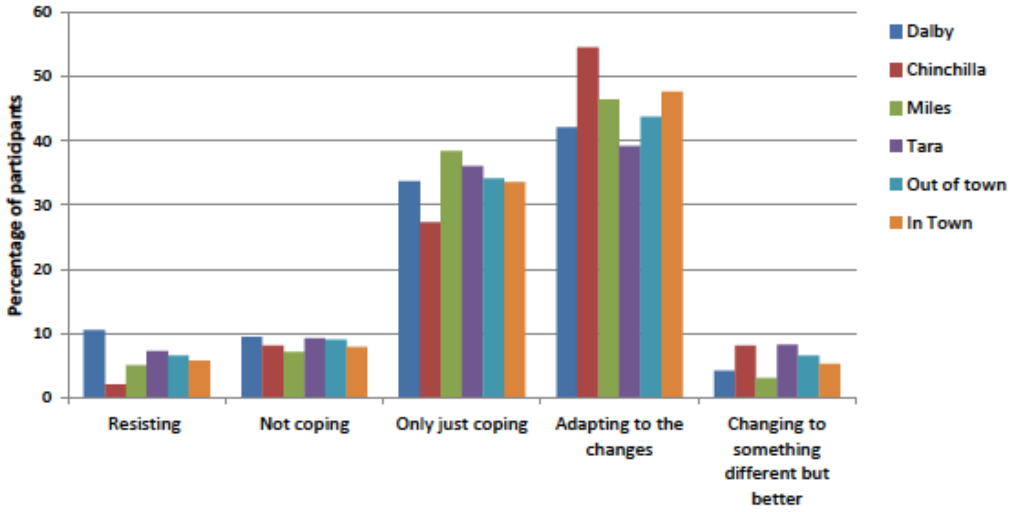
Figure 4: Attitudes towards unconventional gas in the region by suberegions. CSIRO.



Less than a quarter of people surveyed approved of the unconventional gas industry. Only 6% of people felt the community was improving as a result of the industry, while many were struggling to cope with the changes the industry had brought.

[8] Walton, A., McCrea, R., & Leonard, R. (2014). *CSIRO survey of community wellbeing and responding to change: Western Downs region in Queensland.* CSIRO Technical report: CSIRO, Australia.

Figure 5: Community responses to unconventional gas development in the Western Downs Queensland. CSIRO

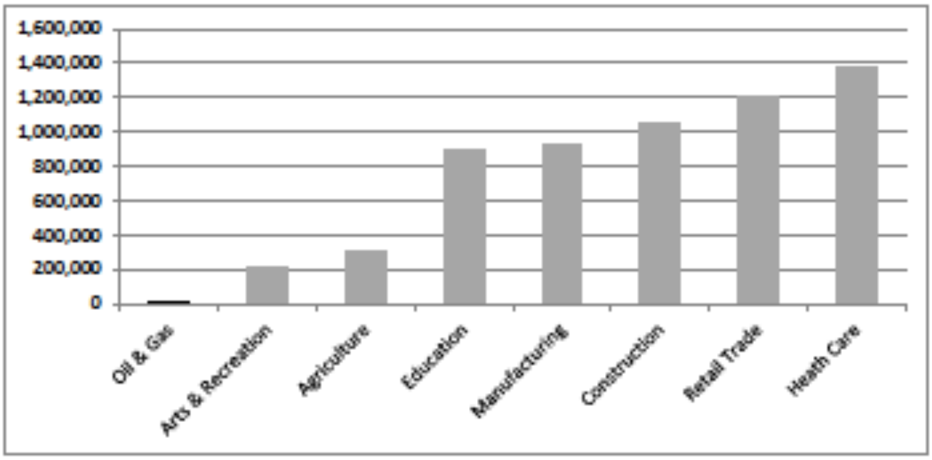


3. Unconventional gas does not employ many people.

According to the Australian bureau of statistics, in May 2015 the entire oil and gas industry in Australia employed 27,500 Australian workers, or less than a quater of 1% of the Australian workforce.[9]

By way of comparison, the total employment provided by the oil and gas industry is considerably less than the retail hardware store Bunning's, which employs 33,000.[10]

Figure 6: Employment in Australia by selected industry.



Employment in the gas industry is likely to decline. The vast majority of gas jobs are during the construction phase. As the construction phase winds up, the unconventional gas companies operating in Queensland are cutting their workforces by around 80%.[11]

Territorians seeking employment for any unconventional project in the Northern Territory will have to compete with experienced workers from interstate. The gas industry requires experienced, skilled workers. With the wind down of the CSG construction boom in Queensland, there is a large pool of highly-qualified workers who

[9] ABS (2013a). *6291.0.55.003 Labour Force, Australia, Detailed, Quarterly, September 2015*, Australian Bureau of Statistics, Accessed 11/11/15, http://www.abs.gov.au/ausstats/abs@.nsf/mf/6202.0

[10] Bunnings (2013). *About Us: Who we are*, Bunnings, viewed 21 November 2013, <http://www.bunnings.com.au/about-us>.

[11] Bureau of Resource and Energy Economics, Resource and Energy Major Projects 2013.

are more likely to fill positions than unskilled Territorians with no experience in gas field construction and operation.

Experience in Queensland has shown that construction workforces are almost entirely male non-residential workers living in workers camps on the outskirts of towns. These workers are often referred to as fly-In, fly-out (FIFO) or drive-in, drive-out (DIDO). Few people from local regional communities are likely to be employed in either the construction or the operational phases of the gas fields.

If locals are employed on these projects, they are unlikely to be previously unemployed people getting a job. When the gas industry employs local people, they tend to be skilled workers who relocate from local manufacturing and agriculture.

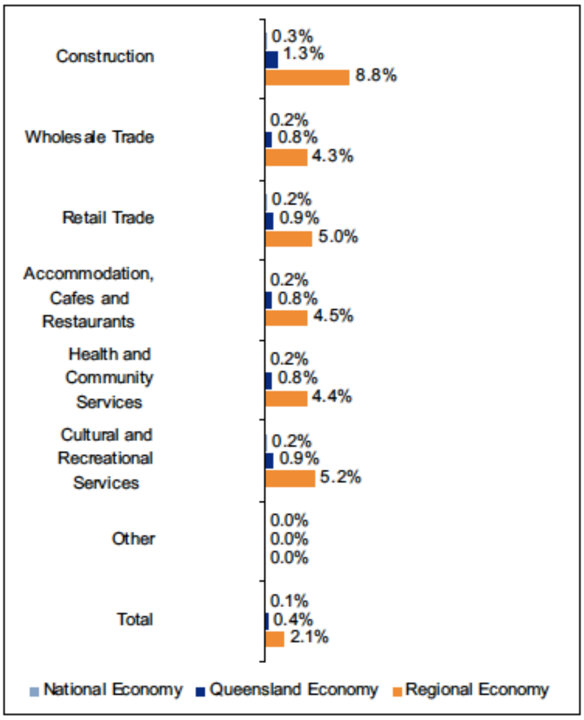
As explained above in section 1, this disrupts local businesses and forces them to compete with inflated gas industry wages to recruit or retain staff.

4. Promise versus reality

As discussed I section 3, the unconventional gas extraction employs relatively few people. These jobs are mostly short term include few people from local regional communities. However the industry claims that the flow on effects result in people being employed elsewhere in the community. However recent rearearch shows that the employment effects have been very different to industry industry claims.

Fore example, the original economic impact statement used to gain approval for the largest unconventional gas project in Queensland, Australia Pacific LNG (APLNG), claimed that the construction phase of the project would increase regional employment in the retail trade by 5 percent, and a range of regional service sectors by between 4.5 and 5.2 percent . [12]

Figure 7: Australia Pacific LNG direct and indirect employment by industry



Source: KPMG, APLNG EIS Economic Impact Assessment report, Chart 5.3 p29

However the reality was very different. At the height of the construction boom in 2013 a study was undertaken by the Gas Industry Social and Environmental Research Alliance (GISERA) into the local economic impacts of the unconventional gas boom.

[12] KPMG, APLNG EIS Economic Impact Assessment report, Chart 5.3 p29.

The study examined the actual economic impacts of unconventional gas development in Queensland's gas fields. As we can see in figure 5 below, the study found that In fact, while there was an increase in short term construction related jobs (construction and professional services), there were virtually no additional jobs in retail or manufacturing as a result of unconventional gas development.[13] A subsequent study by the same authors found that for every ten people employed in CSG, eighteen agricultural jobs were lost. [14]

Figure 8: Unconventional gas employment spillovers in different sectors of Queensland's Darling Downs economy.

	Elasticity	Additional job for each new CSG job
Local goods sector		
Construction	0.832 (0.426) *	1.412
Professional services	0.704 (0.259) **	0.412
Retail trade	0.011 (0.140)	0.024
Services†	-0.205 (0.230)	-0.732
Traded sector		
Manufacturing	0.068 (0.199)	0.160

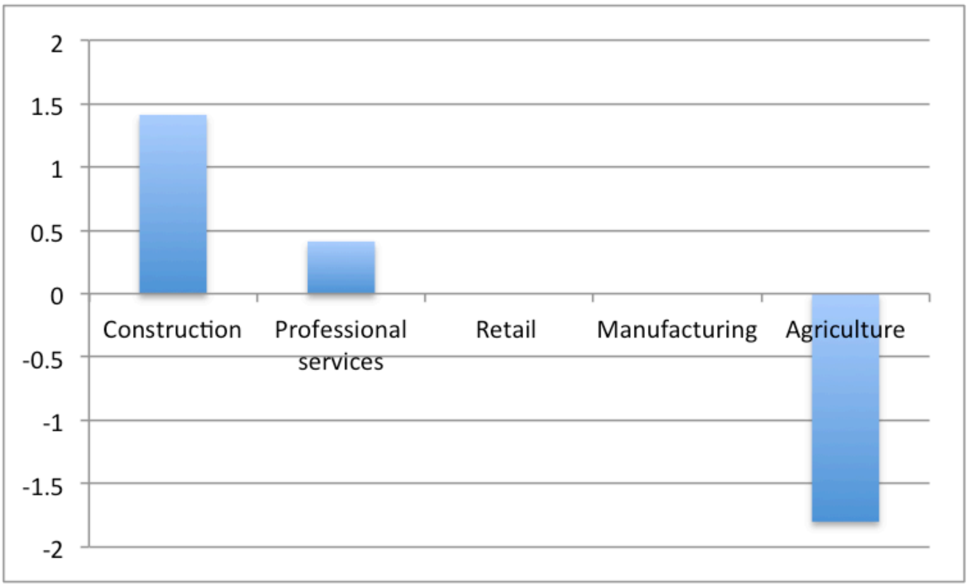
Notes: Elasticity values are 2SLS estimations for coefficient ψ in equation (2). The number of CSG wells in an SLA is used as instrument for the log change of mining employment. Values estimated using sample 3 (n = 48). F-stat first-stage = 10.74. Robust clustered std. errors at LGA levels in parentheses. *p < .10. **p < .05. †Services sector include employment in accommodation, rental agencies, transport and 'other services'.

Source: Flemming and Measham (2013)

[13] Fleming, D. and Measham, T. (2013) Local economic impacts of an unconventional energy boom: the coal seam gas industry in Australia. Report to the Gas Industry Social and Environmental Research Alliance (GISERA). June 2013. CSIRO, Canberra.

[14] Flemming D and Measham T (2015a) Local economic impacts of an unconventional energy boom; The coal seam gas industry in Australia, The Australian Journal of Agricultural and Resource Economics 59(1) pp 78-94

Figure 9 Spillover job impacts per CSG job.



Source: Flemming and Measham 2013 and 2015a

In other words, the unconventional gas boom had virtually no employment benefits outside of the gas industry itself. In the words of the authors, "job spillovers into non-mining employment are negligible". It also shows that agricultural jobs were lost and that the that the jobs benefits employment gains were almost entirely short term construction jobs and (largely construction phase related) professional services jobs.

The Queensland unconventional gas boom is one of the largest and most rapid resource expansions ever seen, and yet it led to virtually no increase in employment in local retail or manufacturing, and a loss of long-term service jobs.

The lack of any increase in retail employment in local communities is largely a result the predominance of no-resident workers living in self-contained workers camps. These employees work long shifts that limit opportunities to spend their income in the local community.

The lack of flow on manufacturing jobs is the result of the gas industry's preference for sourcing materials and equipment from overseas. For example, the huge LNG export and processing facilities at Gladstone in Queensland were entirely designed and built overseas.

All three export terminals were built by the global oil and gas engineering company Bechtel. On their website, Bechtel promote their "efficiency" in not employing Australians. The website page shown in Figure 8 describes all three of the Gladstone LNG Processing plants and export terminals as being designed by Bechtel engineers in

Houston, Delhi and Shanghai, to be built in the Philippines, Indonesia and Thailand. The terminals were then floated over to Australia to be assembled.[15]

Figure 10: Bechtel description of design and construction process for their Curtis Island LNG terminals in Queensland.

An efficient effort

Because of overlapping schedules, close proximity, and good cooperation, each project and all three customers have benefited from economies of scale and efficiency orchestrated by Bechtel.

For the sake of quality, speed, and cost control, Bechtel engineers in Houston, New Delhi, and Shanghai geared their designs for the three Curtis Island plants to modular construction. At Bechtel facilities in the Philippines, Indonesia, and Thailand, colleagues have been building some 250 modules for use in all three complexes.

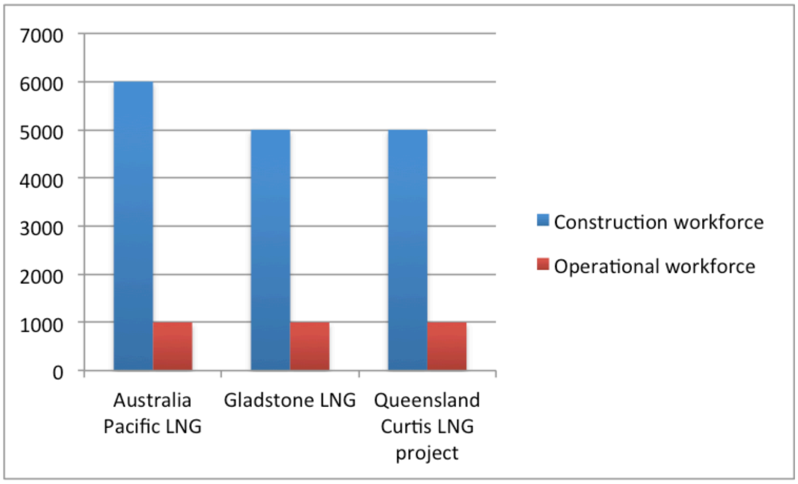
Among the heaviest of 250 modular components: a propane chiller that weighs 2,500 metric tons—equivalent to more than five of the largest 747s, fully loaded.

[15] Bechtel website http://www.bechtel.com/projects/curtis-island-lng/ accessed 10/11/15.

5. Boom and bust

According to the Office of the Chief Economist of Australia, the three unconventional gas projects in Queensland employed 16,000 people during their brief[16] construction phase. This is falling by over 80% to 3,000 employees as the projects enter their operational phase.[17] This will represent less than 0.13% of Queensland's total workforce of over 2.3 million. [18]

Figure 11: Queensland unconventional gas operation and construction employment.



Source: Office of the Chief Economist of Australia (2015).

The construction workforces may have been considerably smaller than reported by the Office of the Chief Economist. The office based the numbers on "fact sheets provided by the companies".[19] APLNG, the largest of Queensland's LNG projects says in its Economic Impact Assessment that "over the 11-year construction phase, there will be an approximate average of 3,300 people working on the Australia Pacific LNG project each year. Employment will peak from 2012 to 2014 inclusive". This is a little over half the number reported by the Office of the Chief Economist but would still represent more than a two-thirds reduction in the workforce between the construction and operational phase.

[16] The length of the construction period varies between the projects. In the case the Gladstone LNG, the construction period was 4 years. URS (2009) GLNG Economic Impact Statement.

[17] Office of the Chief Economist, Resources and Energy Major Projects list April 2015. Viewed on 11 November 2015, <http://www.industry.gov.au/Office-of-the-Chief-Economist/Publications/Pages/Resources-and-energy-major-projects.aspx>

[18] ABS Labour Force Statistics.

[19] Correspondence with the Office of the Chief Economist.

Any unconventional gas project in the Northern Territory would employ far fewer workers than in Queensland.

A large proportion of both the construction and operational workforce in Queensland worked on assembling the LNG terminals at Gladstone. Additional LNG terminals will not be required in the Northern Territory as the gas will be exported via the Queensland terminals.

There is also likely to be a large pool of experienced gas workers in Western Australia and Queensland who are well placed to fill Northern Territory unconventional gas jobs. The three Queensland LNG terminals, the Northern Territory Inpex project and several Western Australian LNG terminals and offshore gas fields were all built simultaneously. The decision to allow all these projects to be built simultaneously created an acute skills shortage at the time. With the wind down of the construction phase of these projects there is an abundance of interstate skilled gas construction workers who will be far better placed to work in any gas projects in the NT than unemployed NT residents who lack these skills.

To the extent that NT residents are employed, they are likely to be skilled workers already employed in other industries, particularly manufacturing and agriculture. This effect drives up costs for other industries as they are forced to compete with the oil and gas industry for skilled workers.

6. Impacts on manufacturing

The unconventional gas industry hurts the manufacturing industry, mostly because they compete for skilled labour. Economic modelling by the Queensland unconventional gas company Arrow LNG for its Economic Imact Assessment found that its project would displace $441.5 million worth of manufacturing output and 1,000 manufacturing jobs in Queensland.[20]

Arrow LNG is just one of the four large unconventional gas projects in Queensland. The full employment impacts of this single project can be seen in Figure 11 below.

While the modelling suggests the project would a create a considerable number of short term construction jobs, these jobs come at the expense of long term jobs in other sectors, particularly manufacturing.

Once extinguished, manufacturing activity is difficult to rebuild. Plants and equipment require a large upfront investment, but only deliver returns over the long term. If a region is likely to experience further disruption from large resource projects, investors are unlikely to have confidence in manufacturing.

Figure 12: Average Annual Impact on Employment by Industry in Queensland of Arrow LNG project.

Industry	Change in Employment (FTEs)			
	2013-14 to 2016-17 (Phase 1 Construction)	2018-19 to 2021-22 (Phase 1 Steady State Operation)	2022-23 to 2024-25 (Phase 2 Construction) (a)	2026-27 to 2029-30 (Phase 2 Steady State Operation) (a)
Queensland				
Agriculture	-59	-24	-66	-42
Mining	-65	-28	-69	-50
Manufacturing	-1,089	-25	-804	-200
Electricity and water	-10	25	39	55
Construction	1,833	127	1,325	257
Trade	221	58	255	130
Transport and storage	-246	-27	-186	-37
Business, finance and insurance services	-132	83	119	166
Public administration, defence, health and education	29	-6	-45	-19
Recreation and other services	22	-4	1	-8
Ownership of dwellings	6	0	3	0
Total Change in Employment in Queensland	**511**	**180**	**571**	**251**

Note: (a) It should be noted that operation of Phase 1 (trains 1 and 2) is ongoing during these time periods.
Source: Prime Research (unpublished).

Source: AEC Group (2011) Arrow LNG Economic Impact Assessment, table 5.3 p.43

[20] Grudnoff, M. (2015) *An analysis of the economic impacts of Arrow Energy's Gladstone LNG Plant.*

As well as higher labour costs, unconventional gas projects have – perversely – increased the cost of gas for manufacturers.

In their Economic Impact Assessment of 2010 GLNG noted that "a relatively mild increase in gas prices associated with the QCLNG Project may occur in the eastern Australian market".[21]

In fact, linking Australian domestic gas prices to higher Asian prices has more than doubled the wholesale gas price.

The recent collapse in the oil price, and subsequently Asian "oil linked" gas prices, has not caused a commensurate reduction in the price of gas being offered to manufacturers. This has led to claims of "cartel like behaviour". [22] The ACCC's ongoing inquiry into the East Coast gas market is investigating "the existence of, or potential for, anti-competitive behaviour and the impact of such behaviour on purchasers of gas".[23]

Economic modeling by Deloitte Access Consulting shows that east coast gas price rises caused by unconventional gas exports have created a $81 billion windfall for the gas industry (mostly global oil and gas majors), but will cost the manufacturing industry $118 billion.[24]

Figure 13: Industry output impacts for Australia as a result of gas price increases.

Table i: Industry output impacts for Australia for the years 2015, 2018 and 2021 and cumulative Net Present Value (NPV) of output impacts over 2014 - 2021

	Value of difference from baseline			% difference			NPV
	2015	2018	2021	2015	2018	2021	Cumulative impact over 2014-2021

[21] GLNG Economic Impact Statement, volume 8 chapter 10, p 12.

[22] West, M. (October 2015) "East coast gas market has all the hallmarks of a cartel". Accessed 11 November 2015, <http://www.smh.com.au/business/comment-and-analysis/east-coast-gas-market-has-all-the-hallmarks-of-a-cartel-20151011-gk6b4i.html>.

[23] ACCC Project Overview, *East Coast Gas Inquiry*. Accessed 11 November 2015, <https://www.accc.gov.au/regulated-infrastructure/energy/east-coast-gas-inquiry-2015>.

[24] Deloitte Access Economics (2014) *Gas market transformations–Economic consequences for the manufacturing sector* Table 1, p 3.

SKM scenario							
Output ($ million)							
Manufacturing	-23,199	-22,259	-30,386	-3.97	-3.48	-4.38	-118,069
Gas	8,922	17,672	24,225	47.81	65.63	57.07	80,746
Mining	-7,226	-6,031	-9,679	-3.55	-2.69	-3.96	-33,804
Agriculture	-1,110	-798	-1,430	-1.98	-1.32	-2.21	-4,705
Electricity and Water	-1,962	-1,989	-2,204	-3.36	-3.09	-3.12	-10,269
Construction and Trade	18,049	2,443	13,265	2.80	0.34	1.69	38,519
Transport	-2,328	-1,988	-3,288	-1.68	-1.31	-2.00	-11,044
Commercial & Services	3,015	-897	649	0.26	-0.07	0.05	1,695

Source: Deloitte Access Economics

Note: The discount rate of 7% was used to calculate the NPV figure.

Source: Deloitte Access Economics (2014)

No amount of additional gas extraction in the Northern Territory or elsewhere will reduce gas prices in Australia as all gas will now go to the Asian market. As the NSW Independent Pricing and Regulatory Tribunal (IPART) put it:

> The increase in regulated retail gas prices 2014/15 reflects increased wholesale gas costs as eastern Australia becomes part of a single global market for commodity gas, as well as increasing network charges.[25]

[25] Inquiry into the supply and cost of gas liquid fuels in NSW, IPART 2014. Accessed 10 July 2015, <http://www.parliament.nsw.gov.au/prod/parlment/committee.nsf/0/efb3f0c1908f7b21ca257dc7000 5b1b 2/$FILE/0023%20-%20IPART.pdf>

7. Big numbers, small benefits

Gas companies often cite the amount of money they invest or the value of the gas they sell as proof of the economic benefits of their projects.

However these numbers say little about benefits for Australians if the money invested in a project is spent on equipment from overseas, profits flow to foreign investors and the companies pay little tax or royalties.

The oil and gas industry in Australia is over 80% foreign owned,[26] which means that over 80% of the profits go directly off shore. It imports almost all its equipment and pays very low rates of tax. The theoretical company tax rate in Australia is 30%. All industries are able to claim exemptions and the average effective company tax rate of all industries in 2011/12 was 17.6%. That year the oil and gas industry in Australia paid an effective company tax rate of 5.4%.[27]

The Queensland LNG projects were approved without an estimate of royalty payments to the state government.

As the Reserve Bank of Australia concluded, while Australian production of LNG is expected to ramp up substantially over the next few years:

> The effect on Australian living standards will be less noticeable than this given the low employment intensity of LNG production, the high level of foreign ownership of the LNG industry and, in the near term, the use of deductions on taxation payments. [28]

The big numbers for capital value or change in GDP tell us little about the benefit of gas exports to the wider Australian economy and community. As the Reserve Bank of Australia notes, these benefits are likely to be smaller.

[26] Calculations by The Australia Institute based on published 2P reserves and production.

[27] Taxation statistics 2011–12, Table 4: Company tax, Selected items by industry, ABS 81550DO002_201112 Australian Industry.

[28] Cassidy, N. and Kosev, M. (2015) Australia and the Global LNG Market, RBA.

4. The Industrial footprint of shale gas

One important way that unconventional gas development differs from other types of resource development is that it covers far greater areas. Mines are generally highly concentrated with relatively small footprints, while unconventional gas fields often cover tens of thousands of square kilometers with an industrial grid of wells, pipelines, access roads, compressor stations and water treatment plants.

The most mature shale gas field in the US, the Barnett Shale has an average of 1.15 wells per square kilometer, but is as high as 6 wells per square kilometer due to “infill drilling” needed to extract gas as fields deplete.[29]

Every shale gas well needs to be fracked multiple times. Every frack requires 11-34 million litres of water[30] equating to 360-11,000 truckloads and “80-300 tonnes of industrial chemicals [31]. This is potentially an enormous increase in truck mvements on the Territory’s roads and will inevitable impact other road users.

Pennsylvania in the United States has a mature shale gas industry. A gas industry study last year in Pennsylvania found that more than 6% of gas wells leaked, and up to 75% of wells could have some form of integrity failure. [32] In Pennsylvania more than 240 private drinking water wells have been contaminated or have dried up as the result of drilling and fracking operations over a seven-year period[33]

[29] Shale Gas Information Platform SHIP. GFZ http://www.shale-gas-information-platform.org/categories/operations/the-basics.html Accessed 10/11/15

[30] UNEP Global Environmental Alert Service: Gas Fracking: Can we safely squeeze the rocks?

[31] Hazen and Sawyer, December 22, 2009. Impact Assessment of Natural Gas Production in the New York City Water Supply Watershed.

[32] Davies, R. J., Almond, S., Ward, R. S., Jackson, R. B., Adams, C., Worrall, F., ... Whitehead, M. A. (2014). Oil and gas wells and their integrity: Implications for shale and unconventional resource exploitation. *Marine and Petroleum Geology, 56*, 239-254. doi: 10.1016/j.marpetgeo.2014.03.001

[33] Concerned Health Professionals of New York & Physicians for Social Responsibility. (2015, October 14). Compendium of scientific, medical, and media findings demonstrating risks and harms of fracking (unconventional gas and oil extraction) (3rd ed.). http://concernedhealthny.org/compendium/

Conclusion

Gas companies routinely exaggerate the economic and jobs benefits of their projects. Policy makers often accept these claims unquestioningly.

The Northern Territory is fortunate to have the Queensland unconventional gas experiment to reflect upon. The Queensland experience is that most of the economic benefits do not materialise, and serious collateral damage is done to existing industries and local communities.

If policy makers in the Northern Territory naively accept the economic claims of speculative gas companies and use taxpayer money to support this industry, Territorians will live the consequences for decades to come.