Fracking by the Numbers

Key Impacts of Dirty Drilling at the State and National Level

Environment America Research & Policy Center

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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.

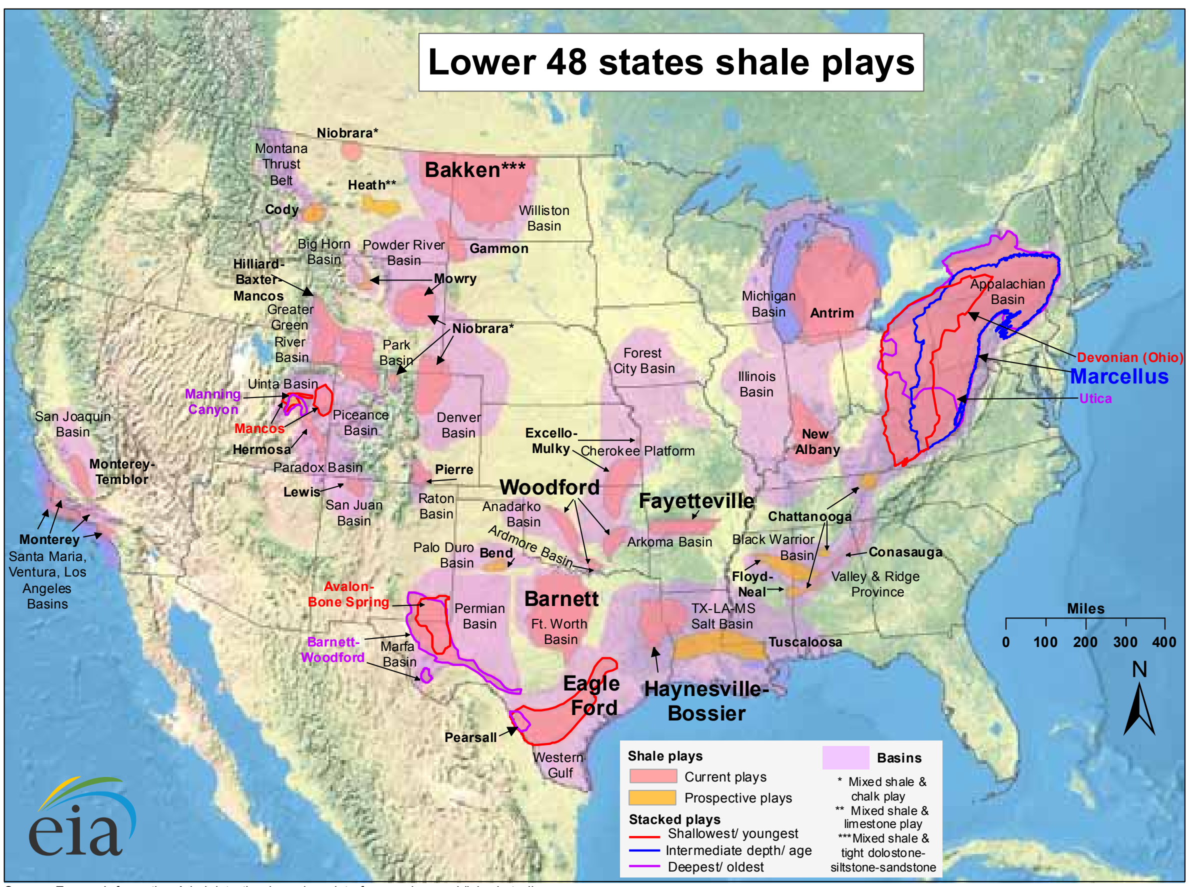
Fracking Poses Grave Threats to the Environment and Public Health

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.

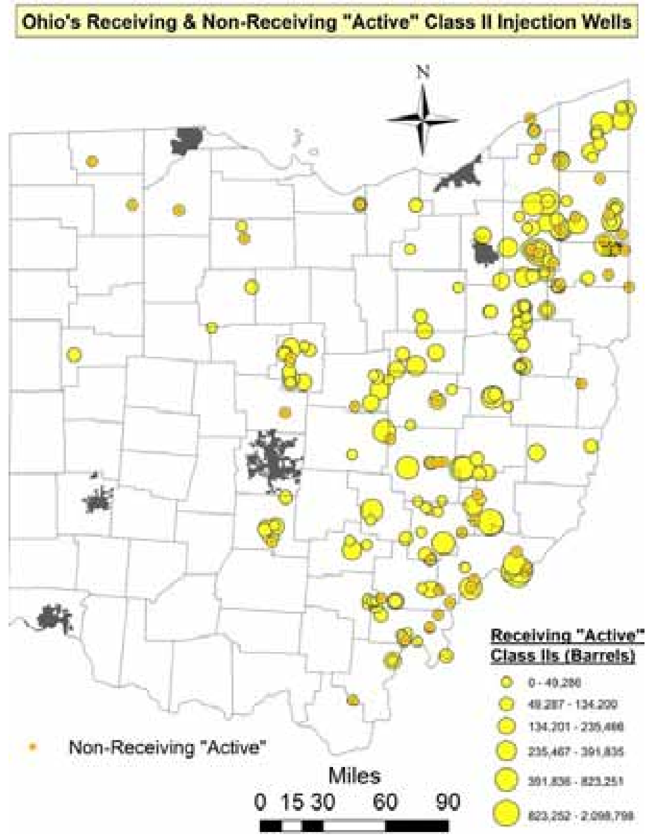
The rapid growth of fracking has caused wastewater volumes to increase rapidly. In the Marcellus Shale underlying Pennsylvania, West Virginia and Ohio, for example, wastewater production increased six-fold from 2004 to 2011.[89]

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://dnrwebmap-gdev.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.

In **North Dakota**, we assumed one well per pad, though that estimate may be less valid for wells drilled in the past year, per Mike Ellerd, "Evolution Continues: Densities Could Reach 24 Wells Per Pad; 6,000 Wells Over Next 3 Years," *Petroleum News Bakken*, 21 April 2013. We assumed the average well occupies five acres of land, per Alison Ritter, Public Information Specialist, North Dakota Industrial Commission Department of Mineral Resources (Oil & Gas Division), personal communication, 8 July 2013. We were unable to obtain a North Dakota-specific estimate of acres disturbed for roads, pipelines and infrastructure and made the assumption that 4.75 acres are damaged, the same as in western Colorado.

In **Arkansas**, we assumed that most of the wells drilled to date in Arkansas were drilled one to a pad, per Jeannie Stell, "Angling in the Fayetteville," *Unconventional Oil & Gas Center*, 15 October 2011. In the Fayetteville Shale, we assumed well pads are 2.1 acres and that associated roads and infrastructure add 2.7 acres, per Dan Arthur and Dave Cornue, ALL Consulting, "Technologies Reduce Pad Size, Waste," *The American Oil & Gas Reporter*, August 2010.

Notes

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3. Laura Legere, "Sunday Times Review of DEP Drilling Records Reveals Water Damage, Murky Testing Methods," *The Times-Tribune* (Scranton, Pa.), 19 May 2013.

4. New Mexico Oil Conservation Division, Environmental Bureau, *Generalized Record of Ground Water Impact Sites*, accessed at www.emnrd.state.nm.us/OCD/documents/rptGeneralizedGWImpact.pdf, 20 September 2013.

5. Theo Colborn, et al., "Natural Gas Operations from a Public Health Perspective," *Human and Ecological Risk Assessment: An International Journal*, 17(5): 1039-1056, 2011, doi: 10.1080/10807039.2011.605662.

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