THE URGENT CASE FOR A BAN ON FRACKING

food&water europe

About Food & Water Europe

Food & Water Europe works to ensure the food, water and fish we consume is safe, accessible and sustainable. So we can all enjoy and trust in what we eat and drink, we help people take charge of where their food comes from, keep clean, affordable, public tap water flowing freely to our homes, protect the environmental quality of oceans, force government to do its job protecting citizens, and educate about the importance of keeping shared resources under public control.

Food & Water Europe has an office in Brussels to help engage concerned citizens across Europe on the issues they care about.

Brussels Office
26, rue d'Edimbourg
1050 Brussels
Belgium
0032 (0)2 893.10.45

This report can be viewed or downloaded at **foodandwatereurope.org.**

Letter from Wenonah Hauter

Executive Director, Food & Water Europe

In many ways, fracking is the environmental issue of our time. It's an issue that touches on every aspect of our lives — the water we drink, the air we breathe, the health of our communities — and it is also impacting the global climate on which we all depend. It pits the largest corporate interests — big oil and gas companies and the political leaders who support them — against people and the environment in a long-term struggle for survival. It is an issue that has captivated the hearts and minds of hundreds of thousands of people across the United States, Europe and across the globe. And it is an area in which, despite the massive resources of the Frackopoly — the cabal of oil and gas interests promoting this practice — we as a movement are making tremendous strides as our collective power continues to grow.

Food & Water Europe is proud to work shoulder to shoulder with communities across Europe and across the world in this effort. With mounting evidence about the harms of fracking and the immediacy of the impending climate crisis, this report lays out the urgent case for a ban on fracking.

In 2009, we became alarmed about the threat that hydraulic fracturing (fracking) posed to water resources across the United States. Communities around the United States were already raising the alarm about the ill effects that fracking was having, from increased truck traffic to spills and even tap water that could be lit on fire thanks to methane leaks from fracking wells into water sources.

Meanwhile, many national environmental groups were touting natural gas as a "bridge fuel" — a better means of producing energy from fossil fuels than coal, a source that everyone knew we had to move away from urgently to reduce the carbon emissions that were heating the planet at a dangerous rate. Communities that were already feeling the effects of the technology, or that were fighting the coming wave of fracking, felt betrayed that the place they lived could become one of the sacrificial zones — with many environmentalists' blessing. Over the next few years, scientific evidence would mount that not only is fracking not climate friendly, but it has the potential to unleash massive amounts of methane that will contribute to climate disaster.

So we began our work on fracking with *Not So Fast, Natural Gas*, our report that raised serious questions about fracking safety and the natural gas rush being promoted by industry and government. That report, released in 2010, called for a series of regulatory reforms, but the evidence continued to mount. The next year, after looking at even greater evidence of the inherent problems with fracking, and realizing how inadequately the states were regulating the oil and gas industry and enforcing those regulations, Food & Water Europe was one of the first European organisations to call for a complete ban on fracking and we released the report *The Case for a Ban on Gas Fracking*.

Since the release of that report in 2011, more than 150 additional studies have been conducted on a range of issues — from water pollution to climate change, air pollution to earthquakes — reinforcing the case that fracking is simply too unsafe to pursue. In the face of such studies, and following the lead of grassroots organizations that have been at the forefront of this movement, a consensus is emerging among those working against fracking that a ban is the only solution. Not only are decision-makers not regulating the practice of fracking, it is so dangerous and the potential so great that it cannot be regulated, even if there were the political will.

As this report lays out, there is mounting evidence that fracking is inherently unsafe. Evidence builds that fracking contaminates water, pollutes air, threatens public health, causes earthquakes, harms local economies and decreases property values.

And most critically for the survival of the planet, fracking exacerbates and accelerates climate change. We are facing a climate crisis that is already having devastating impacts and that is projected to escalate to catastrophic levels if we do not act now. Our elected officials tout fracked gas as a "bridge fuel," yet mounting evidence suggests that rather than serving as a bridge to a renewable energy future, it's a bridge to a climate crisis.

While the environmental, public health and food movements have looked at mounting evidence and rejected fracked gas and oil, President Obama and his administration have aggressively promoted natural gas and domestic oil as a critical part of the United States' energy future. President Obama repeatedly touts domestic gas production and has said that "we should strengthen our position as the top natural gas producer … [I]t not only can provide safe, cheap power, but it can also help reduce our carbon emissions." His Energy Secretary Ernest Moniz has close industry ties and has claimed that he has "not seen any evidence of fracking per se contaminating groundwater" and that "the issues in terms of the environmental footprint of hydraulic fracturing are manageable."

Despite what the US government and industry claim, there have now been over 150 studies on fracking and its impacts that raise concerns about the risks and dangers of fracking and highlight how little we know about its long-term effects on health and our limited freshwater supplies. It's time for our elected leaders to look at the facts and think about their legacy. How do they want to be remembered? What do they want the world to look like 20, 50 and 100 years from now?

We first made the case for a ban on fracking in 2011, but this new report shows that there is an urgent case for a ban. The evidence is in, and it is clear and overwhelming. Fracking is inherently unsafe, cannot be regulated and should be banned. Instead, we should transition aggressively to a renewable and efficient energy system.

THE URGENT CASE FOR A BAN ON FRACKING

TABLE OF CONTENTS

Executive Summary

The term "fracking" has come to mean more than just the specific process of injecting large volumes of various mixes of water, sand and chemicals deep underground, at extreme pressure, to create fractures in targeted rock formations — all so tightly held oil and gas might flow.

We now use the term fracking to represent all that this specific process of hydraulic fracturing entails. Allowing more fracking means that oil and gas companies will continue to:

- **Fragment forests and mar landscapes** with new roads, well sites, waste pits and pipelines;
- **Compete with farmers for local water supplies** while consuming millions of liters of water for each fracked well;
- **Produce massive volumes of toxic and even radioactive waste**, the disposal of which is causing earthquakes and putting at risk drinking water resources;
- **Cause thousands of accidents, leaks and spills** each year that threaten public health and safety and put at risk rivers, streams, shallow aquifers and farms;
- **Pump hazardous pollutants into the air**, at the expense of local communities, families and farms;
- **Turn homes into explosive hazards** by contaminating water wells with methane and other flammable gases;
- **Put vital aquifers at risk for generations** by creating new pathways for the potential flow of contaminants over the coming years and decades;
- **Destabilize the climate on which we all depend** with emissions of carbon dioxide and methane and by locking in future climate pollution with new oil and gas infrastructure projects; and
- **Disrupt local communities**, with broad physical and mental health consequences, increased demand on emergency and other social services, damage to public roads, declines in property value, increased crime, and losses felt in established sectors of local economies.

In 2011, Food & Water Europe called for a ban on fracking because of the significant risks and harms that accompany the practice. Now, over three years later, numerous peer-reviewed studies published in scientific, legal and policy journals have expanded what is known — and clarified what remains unknown — about the environmental, public health and socioeconomic impacts that stem from fracking. In this report, Food & Water Europe reviews the science and renews its call for a ban.

We find that the open questions amount to unacceptable risk, and that the harms are certain. Stringent regulations, even if put in place and even if adequately enforced, would not make fracking safe. Municipal bans, moratoria and zoning laws are being passed to try to protect communities across the country, but federal and state level action is necessary to reverse the spread of fracking.

The only path to a sustainable economic future is to rebuild the our energy system and local economies around safe energy solutions: efficiency, conservation and renewable resources. Fracking takes us in the wrong direction.

Introduction

Hydraulic fracturing allows oil and gas companies to target underground layers of rock that hold oil and gas, but that do not readily allow the oil and gas to flow up a well. Drilling through these rock formations, then injecting a blend of water, sand and chemicals at extreme pressure, creates fractures propped open by the sand, exposing otherwise tightly held oil and gas and allowing it to flow.

PHOTO BY HENDRIK VOSS

In response to declines in conventional production, and to the lack of access to many international sources of oil and gas,[1] companies are now fracking in the United States on an unprecedented scale. (See Box 1.) Acids are also being injected, particularly in California and perhaps increasingly in Florida, to eat away new pathways for oil and gas to flow, with or without creating new fractures.[2]

The oil and gas industry enjoys favored status under the law and an entrenched position in U.S. politics, economics and institutions. This creates an inertia that imperils current and future generations, and endangers our economy, as we face the consequences of global warming and the legacy of the industry's pollution.

The current status quo at the federal level, and in many states, is to encourage as much drilling and fracking for oil and gas as possible. Increased political and legislative gridlock in Washington, D.C. has helped to maintain this status quo.[14] Those with large stakes in oil and gas production — a tangle of oil and gas companies, engineering and construction firms, environmental consultancies, trade associations, public relations and marketing firms, financial institutions and large individual investors — stand to profit from this status quo.

Revolving doors and structural ties between the industry and state and federal agencies,[15] academic research groups that act as satellite industry labs and think tanks,[16] and industry control of access to data and sites,[17] as well as technical expertise,[18] all illustrate the extent of the oil and gas industry's capture of U.S. energy policy. The oil and gas industry's influence is reflected in the exemptions that it enjoys in key provisions of all of the landmark environmental laws, including the Clean Air Act, the Safe Drinking Water Act, the Clean Water Act and laws regulating hazardous wastes.[19]

Over a trillion dollars in "sunk" costs in infrastructure favors the status quo of dependence on the oil and gas industry, serving as a barrier to the remaking of the U.S. energy system.[20] The oil and gas industry receives about $4 billion each year in direct taxpayer-funded subsidies.[21] The Sierra Club and Oil Change International recently calculated that subsidies to the fossil fuel industry in 2009 and 2010 amounted to a 59 to 1 return on the money that the industry spent those years on lobbying and on financing political campaigns.[22] The European Union should not follow the energy policies that have prevailed in the US

In this report, Food & Water Europe summarizes recent scientific literature on the water pollution, landscape changes, air pollution, climate pollution and waste disposal problems brought on by drilling and fracking for

Box 1 • *The scale of fracking*

To hydraulically fracture a modern onshore oil or gas well, batches of millions of liters of water, tons of sand and thousands of liters of chemicals get injected repeatedly, typically in tens of stages along a two and a half kilometer long, several-inches-wide tunnel, or borehole, that runs laterally through a targeted rock formation thousands of feet below ground. Oil and gas companies are now doing this more than 10,000 times each year in the United States to extract so-called shale gas, tight gas and tight oil.[3] Acids are commonly used in the fluids that the companies inject, to eat away pathways for oil and gas to flow, and this is not always done at pressures high enough to induce fractures. The extent of offshore fracking is largely unknown, but the practice is clearly on the rise and a focus of the oil and gas industry.[4]

In 2012, the U.S. Energy Information Administration estimated that bringing the projected amounts of technically "recoverable" — as if recovering something lost — shale gas and tight oil into production would require drilling and fracking over 630,000 new onshore wells.[5] If this happens, many thousands of the wells envisioned are likely to have cementing and casing issues from the outset, and all of them will age and degrade over subsequent years and decades, putting at risk underground sources of drinking water.[6] Given that initial fractures release just a small fraction of the oil or gas held in targeted source rocks, industry will also seek to re-fracture many thousands of these wells to try to reverse the typically rapid declines in production as they age.[7]

A 2013 analysis from the *Wall Street Journal* found that over 15 million Americans are living within one and a half kilometers of a well drilled after the year 2000, when large-scale hydraulic fracturing operations began.[8] Many more live alongside other polluting infrastructure that supports oil and gas production, including processing plants, compressor stations and refineries. Hundreds of communities have passed actions in opposition to drilling, fracking and supporting infrastructure.[9]

Oil and gas companies have piled up over $100 billion in debt, in large part to support drilling and fracking and related infrastructure.[10] Data from the major publicly listed oil and gas companies show that from 2008 to 2012, collective capital spending increased by about 32 percent, while, at the same time, oil production fell by about 9 percent.[11] Evidently the industry is banking that increased drilling and fracking into the future, coupled with increased oil and natural gas exports, will translate to profits eventually, presuming that oil and gas prices rise.[12] Industry's bubble will burst, not least because society's systematic dependence on fossil fuels is posing an existential threat by destabilizing our climate.[13]

oil and gas. These impacts are due in large part to the toxic nature and pervasive spread of the chemical pollutants that the industry brings to the surface. (See Box 2.) Recent research further reveals how these and other impacts collectively damage public health and disrupt communities.

Put simply, widespread drilling and fracking for oil and gas is inherently unsafe and terribly shortsighted. This report explains why it is time for a ban. The oil and gas industry's corrupting influence on American policy and government threatens to continue the harm, and to continue to supplant proven and safe solutions for meeting energy needs.

Water and Land Impacts

The oil and gas industry's capture of U.S. energy policy has colored several high-profile investigations of aquifer contamination in the aftermath of drilling and fracking, namely in Pavillion, Wyoming, in Dimock, Pennsylvania, and in Parker County, Texas.

Box 2 • *The pollutants that the oil and gas industry brings to the surface*

"Natural gas," "natural gas liquids," "crude oil," "drilling muds" and "produced water" are innocuous-sounding terms that conceal the nature of all that the oil and gas industry brings to the surface.

Hydrocarbons are just molecules that consist primarily of hydrogen and carbon atoms, bound together. A mix of hydrocarbons is called crude oil when the bulk of the hydrogen and carbon atoms that make up the mix are bound together in large molecules, and the mix is liquid when it reaches the surface.[23] The term natural gas liquids refers to a variety of different mixes of hydrocarbons that consist mostly of lighter hydrocarbons — ethane (C_2H_6), propane (C_3H_8), butanes (C_4H_{10}) and other lightweight hydrocarbon chains — that happen to be somewhat wet to the touch at moderate temperatures and pressures.[24] The term natural gas is used broadly to refer to various gases that are made up primarily of methane (CH_4),[25] a potent greenhouse gas[26] and a primary driver of global warming.[27] But drilling and fracking brings much more to the surface than just these hydrocarbons.

Generally, the liquids and gases that flow to the surface arrive as mixes of fracking fluid, brines and hydrocarbons; the chemical compositions vary in time and vary from well to well, but are otherwise not well characterized.[28]

Many of the hydrocarbons brought to the surface are hazardous pollutants, including volatile organic compounds (VOCs), such as benzene, toluene, enthylbenzene and xylenes (collectively known as "BTEX"), as well as polycyclic aromatic hydrocarbons.[29]

Drilling and fracking can also bring various amounts of hydrogen sulfide, arsenic and selenium to the surface, along with ancient salt waters, or brines.[30] The brines differ in composition according to the nature of the targeted rock formation, and typically contain salts (including "chlorides, bromides, and sulfides of calcium, magnesium and sodium"[31]), metals (including "barium, manganese, iron, and strontium, among others"[32]), and radioactive material (including radium-226) and byproducts of radium decay (including lead and radon).[33]

Finally, oil and gas companies bring to the surface various amounts of the chemicals used in fracking, and byproducts from reactions involving these chemicals.[34] Given trade-secret protections in federal and state laws, and otherwise inadequate disclosure requirements, the actual chemical composition of any given fracking fluid injection is unknown, often even to the company doing the injecting.[35] What is known is that fracking fluids often have toxic compounds, including methanol, isopropyl alcohol, 2-butoxyethanol, glutaraldehyde, ethyl glycol and BTEX.[36] Hydrofluoric and hydrochloric acids are also commonly used to clear out new pathways for oil and gas to flow, at times without actually inducing new fractures.[37]

"Mud pit" on a Bakken shale drilling site.

With the exception of the fracking chemicals and the byproducts of any fracking chemical reactions, all of the above chemical pollutants had long been safely sequestered and immobilized, deep underground. Now, drilling and fracking brings these pollutants to the surface at baseline levels that risk human health and environmental damage through water, soil, air and climate pollution. Then there are the greater-than-baseline levels of contamination: the accidents, leaks, spills and explosions that are proving difficult to predict and expensive and dangerous to clean up, to the extent that they can be cleaned up.

The liquids, sludge and solids that remain from what the industry does not leak into the air, spill on the ground, burn or otherwise use, are adding up to create waste disposal problems. This pollution is part and parcel of the current "all-of-the-above" approach to U.S. energy policy. All of the above pollutants need to stay underground.

In December 2011, the U.S. Environmental Protection Agency (EPA) published a draft scientific report on groundwater contamination in Pavillion, Wyoming, stating that waste pits likely contaminated shallow groundwater[38] and that data on chemicals detected in a deeper monitoring well "indicates likely impact to ground water that can be explained by hydraulic fracturing."[39] The draft report called for more monitoring of wells to make the findings of the report more definitive.[40] In the face of extreme pressure from the industry and from industry advocates in Congress, however, the EPA decided in 2013 to abandon finalizing the report.[41] Instead, the EPA deferred it to the State of Wyoming, which will rely on the company implicated in the case to fund a new investigation.[42] While the EPA claims that it still "stands behind its work and data,"[43] the retreat was widely reported as a victory for the industry.[44]

In 2012, the EPA similarly retreated from its investigation of water contamination cases in Dimock, Pennsylvania,[45] which the state's environmental agency had determined were due to "drilling activities."[46] The EPA had found contaminants in several of the water wells in question, but simply stated that "the residents have now or will have their own treatment systems that can reduce concentrations of those hazardous substances to acceptable levels at the tap."[47] The EPA failed to evaluate the reasons for the contamination, again leaving the public with the false impression that affected residents' claims of contamination had no merit.[48]

In December 2014, the EPA will issue a draft of a multi-year study on the potential impacts of fracking on drinking water resources. In this study, the agency is relying heavily on voluntary cooperation from the oil and gas industry for data and expertise. This reliance on industry partly explains the EPA's retreat on the third high-profile case of contamination linked to drilling and fracking, in Parker County, Texas.[49] According to the EPA's Inspector General, a primary reason that the agency withdrew its emergency order against the company doing the drilling and fracking was that the company agreed to participate in the EPA's ongoing study.[50] This episode, in particular, highlights how the industry's control over data and expertise shapes the science and investigations carried out on behalf of the public.

The residents of Parker County, Dimock and Pavillion went to the EPA because they did not feel that their respective states were being responsive to their concerns. Texas, Pennsylvania and Wyoming each have long histories of promoting oil and gas development, in the name of preventing "waste" of oil and gas reserves,[51] and are party to interstate resolutions to encourage

Land is cleared for drilling and fracking in Pennsylvania.

shale gas extraction and "expansion of natural gas infrastructure."[52] The EPA's unwillingness to complete investigations of these three landmark cases of drinking water contamination means that the affected residents have nowhere else to turn.

Generally, the risks and impacts to water resources include the industry's competition for water, land and surface water pollution, and aquifer contamination.[53]

Water consumption

Affordable access to clean water is a public health issue, and a human right. Public water systems already face major challenges that will be exacerbated by global warming, in the form of locally severe droughts, extreme storms and otherwise altered rainfall, snowfall and snowmelt patterns.[54] Over a century of climate pollution stemming from the oil and gas industry contributes significantly to this warming.[55]

Now, with widespread drilling and fracking, the oil and gas industry is not just adding more climate pollution, it is adding significant demand for fresh water in already water-stressed regions of the country. Even worse, it is leaving a legacy of water pollution and landscape disturbance.

Water use per well varies by region, but companies typically require about 20 million liters of water to drill and frack a single shale gas or tight oil well.[56] Some horizontal wells in the Eagle Ford shale play in Texas have been fracked with more than 49 million liters each.[57] Estimates vary as to how much injected fluid returns, from between 5 and 50 percent.[58] In the Marcellus region, between the first stage of fracking and the time the new well is put into production, the liquid that flows up the well amounts to only about 5 percent of the volume injected.[59] Thus, almost all of the water used in fracking fluids is not available for reuse, and is underground indefinitely.

Oil and gas advocates claim that their water use is low relative to overall water use, but statistics that average over large regions are deceptive. Fracking's use of water can be intensive, happening all in a local hotspot for drilling and fracking and all at once for each new well.

Cold-water streams in northern Pennsylvania, where Marcellus shale development is concentrated, have relatively small flow rates,[60] yet withdrawals for fracking have been primarily from surface waters, with withdrawals from public water systems industry's second choice.[61] Regulators anticipate increased use of groundwater in the region over the coming years if the pace of drilling and fracking continues.[62]

A 2014 report by Ceres looked at industry-reported data on 39,294 oil and gas wells fracked between January 2011 and May 2013, and determined that 39 percent were in regions with "high water stress" and 8 percent were in regions with "extremely high water stress."[63] Water stress is a measure of water competition in a region, and regions with "high water stress" are those where total water withdrawals (not just for fracking) make up 40 to 80 percent of the total water available for withdrawal, while "extremely high water stress" means that more than 80 percent of available water is being withdrawn.[64] The report also determined that over 36 percent of the oil and gas wells included in the study were in regions that will "experience groundwater depletion."[65]

To frack the Barnett Shale in Texas, oil and gas companies used groundwater and surface water in equal measure until 2006, and increased the use of surface water to about 70 to 80 percent of total water use from 2007 to 2010, but have since increased groundwater withdrawals.[66] The groundwater withdrawals are primarily from the Trinity aquifer, which is "among the most depleted aquifers in the state."[67]

Water tanks lined up in preparation for fracking.

A particular concern is the extent to which oil and gas companies are competing with farmers for access to limited freshwater resources. In 2012, at a Colorado auction of water rights, oil and gas companies were the top bidders, driving up water prices for the state's farmers, many of which were enduring severe drought conditions.[68] In New Mexico, some farmers affected by severe drought conditions are, in lieu of farming, selling their rights to irrigation water to oil and gas companies.[69]

This competition with, or outright displacement of, agricultural water use will only increase if unconventional oil and gas development continues to expand in counties that already face water stress, and that are likely to experience even larger water supply problems as a consequence of climate change.

Impacts on surface waters, forests and soils

The construction of new well sites and supporting infrastructure are just the first stage in the industry's harm to surface waters, forests and soils. Each Marcellus Shale gas well pad sits on about three acres of cleared land, and for each site another six acres is cleared to build supporting access roads, pipelines and other fossil fuel infrastructure.[70] The industry's construction projects increase the amount of sediment that flows into rivers and streams, causing ecological harm that is compounded by excessive water withdrawals.[71]

Forests and agricultural lands provide watershed-scale filtration as rainwater and snowmelt flow into rivers and recharge aquifers.[72] Widespread shale development in the Marcellus region is expected to cover hundreds of thousands of acres with surfaces that are impervious to rains, significantly disrupting this filtration.[73] New industry sites, pipelines and roads also expose more forest to more clearing, changing the balance of wildlife, harming forest health and thus further affecting watersheds and groundwater recharge.[74] Air pollutants, including ozone, can also harm forests and agricultural lands that are downwind of oil and gas operations.[75]

Water quality in rivers, streams and shallow aquifers, and soil quality on agricultural lands, are further threatened by spills of fracking chemicals and of toxic oil and gas industry wastes, as well as by intentional spreading of the wastes, for example, to de-ice roads given the salts in the wastes.[76] A recent study near active drilling and fracking operations in Colorado found elevated levels of known and suspected endocrine disruptors in surface waters and shallow groundwaters, consistent with what would be expected from spills of the chemicals used by the industry in fracking fluids.[77]

The oil and gas industry's wastes — primarily the leftovers of what's brought to the surface — contain corrosive salts, radioactive material, toxic metals, hydrocarbons, and fracking chemicals, as outlined in Box 2 (page 4). Each year thousands of leaks, blowouts and spills from the oil and gas industry involve these wastes, as well as various fracking chemicals yet to be injected, and/or produced oil and natural gas liquids. (See Box 3.)

In a shining example of the oil and gas industry's capture of regulatory policy, the industry's hazardous wastes from drilling and fracking are exempted from federal regulations on hazardous waste, simply by virtue of having been generated by the oil and gas industry.[78] If wastes with similar characteristics were to be generated by another industry, they would be deemed hazardous.[79]

The liquid wastes that do not get spilled are typically sent to industrial treatment facilities, processed for reuse or injected back underground into disposal wells.[87] In Pennsylvania, about half of the flowback waste is sent to industrial treatment facilities, about one third is reused and increasing amounts are injected back underground into disposal wells, commonly after being sent to Ohio or West Virginia.[88] In Texas, Oklahoma and North Dakota, the dominant practice is to dispose of liquid wastes by injecting them back underground.[89] In California, regulators have recently halted the waste injections at numerous wells out of concern that the wastes are being injected directly into aquifers.[90]

Treatment at industrial waste facilities is imperfect, allowing contaminants to flow through into rivers and streams. In 2013, scientists reported tests on sediment from the bed of Blacklick Creek, in Pennsylvania, at the point where effluent flowed into the creek from an industrial treatment plant with a history of accepting oil and gas industry wastes.[91] The sediment contained greatly enhanced levels of radioactive material, with radiation at 200 times the level found in background sediments.[92] Not only does this put at risk those who eat fish that rely on the food chain from this stream, but it illustrates that treatment is not necessarily effective. Baseline levels of pollution, with some larger pollution events, are inherent to drilling and fracking for oil and gas.

To the extent that treatment is effective, it concentrates the contaminants and thus generates solid waste. Toxic hydrocarbons, heavy metals and radioactive material also become concentrated in sludge at the bottoms of waste pits and in sludge and scale deposits within equipment, such as within pipes and tanks.[93] Radiation from these concentrated wastes, or from the rock cuttings brought to the surface during drilling, is setting off detectors at the gates to landfills.[94] Massive quantities of low-level radioactive wastes pass through these detectors, whether operational or not, and get dumped in landfills,[95] if they are not first spilled beside a road on the way to a landfill.[96] The industry's radioactive solid wastes are also being illegally dumped.[97]

Under a previous governor, North Carolina's Department of Environment and Natural Resources warned that layers of cuttings could result in plugging of the landfill and to eventual spills of fluid, known as landfill

Box 3 • *Accidents and spills are business as usual*

In 2008, *ProPublica* examined local and state government documents from just Colorado, New Mexico, Alabama, Ohio and Pennsylvania and identified more than 1,000 cases of leaks and spills at oil and gas industry sites.[80] According to the *Denver Post*, the oil and gas industry has reported about 2,500 spills in Colorado since the beginning of 2010, with about 6 percent having contaminated surface water and 17 percent having contaminated groundwater.[81] In North Dakota in 2011, the oil and gas industry also reported over 1,000 spills.[82] An analysis by *Energy & Environment* looked at available data and counted over 6,000 "spills and other mishaps" in 2012 alone from oil and gas industry operations throughout the United States, and found that the incidents seldom led to fines.[83] A subsequent analysis found "at least 7,662 spills, blowouts, leaks and other mishaps in 2013 in 15 top states for onshore oil and gas activity."[84] In Pennsylvania, the Department of Environmental Protection has recorded 209 incidents in which the oil and gas industry either contaminated or reduced the flow of water supplies.[85]

All of these estimates are conservative, given that they consist only of incidents that are identified, that meet specific state requirements for reporting, and that actually get reported. Indeed, some mishaps are difficult to identify. A PhD thesis in Petroleum Engineering, completed in May 2014 at Louisiana State University, explains that underground blowouts may just appear to occur less frequently than those that reach the surface, because the effects are hidden underground.[86]

leachate, that is enriched with diverse contaminants, including the radioactive material.[98] Given that the half-life of radium-226 is 1,600 years, such spills would taint the surrounding soil and watershed for centuries.[99]

Surface-water contamination also results when conventional wastewater treatment facilities that are not equipped to treat fracking wastewater nonetheless receive it. The contaminants can pass right through these facilities and be discharged into rivers, causing problems for water systems downstream, as well as for aquatic life.[100] When downstream water utilities disinfect river water with elevated levels of chloride or bromide — two salts that characterize fracking wastewaters[101] — the resulting chemical reactions can form harmful byproducts that are linked to cancer and birth defects and yet are difficult to remove once present in drinking water supplies.[102]

Rather than simply not allow surface disposal, the EPA is drafting rules that would require "pre-treatment" of shale gas wastewaters before these wastes could be sent to conventional treatment facilities that serve public water systems.[103] And since fracking is also occurring in non-shale formations, guidelines for only shale formations are inadequate. However, as is the case with rounds of wastewater recycling and industrial treatment, this sole pre-treatment concentrates the toxins, creating new disposal problems.

Aquifer contamination

In addition to contaminating farmland and watersheds,[104] plumes from leaks and spills of liquids at the surface can seep down into soil and can contaminate shallow aquifers, as a significant fraction of spills have done in Colorado.[105] But aquifers also face unseen threats from below, both immediate and over the long term.

Disproportionately high levels of arsenic, as well as strontium, selenium and barium, have been identified in groundwater in areas of the Barnett Shale region in Texas that have seen more oil and gas activity.[106] The presence of these contaminants was believed to be due to their increased mobility, as a consequence of either nearby water withdrawals or mechanical disturbances, such as vibrations introduced during drilling and fracking.[107]

In a handful of incidents, oil and gas companies have injected fracking fluids or oil and gas industry wastes very close to, if not directly into, underground sources of drinking water.[108] Beyond these cases of direct contamination, a network of different pathways can allow contaminants to indirectly seep into and contaminate groundwater from below, in the aftermath of drilling and fracking.[109] The pathways include new fractures created by hydraulic fracturing, existing natural fractures and faults, and openings along wells with compromised construction, or integrity.[110]

Methane and other hydrocarbon gases

A study published in 2000 estimated that tens of thousands of oil and gas wells in North America were leaking gas, including into the atmosphere and into shallow aquifers.[111]

In 2011, scientists observed that methane concentrations in samples from water wells located in regions of active Marcellus and Utica shale gas development were 17 times higher, on average, compared to samples from water wells in regions without drilling and fracking activity.[112] The authors concluded that "leaky well casings" were the most likely cause.[113] In 2013, several of the same scientists studied 141 wells in Pennsylvania and found higher methane concentrations — by a factor of six on average — in water wells located less than about 3,200 feet (i.e., 1 kilometer) from a natural gas well, compared to water wells located farther away from any natural gas well.[114]

While methane itself may not be toxic, its presence in aquifers indicates the presence of other hydrocarbons that are toxic. (See Box 2, page 4.) When a mix of hydrocarbon gas enters unventilated spaces through contaminated water wells, it can cause suffocation and even result in explosions.[115] Methane that contaminates aquifers may also, through geochemical reactions or other mechanisms, increase levels of arsenic and other harmful toxins in water brought to the surface.[116]

Ultimately, the methane and other hydrocarbons may or may not originate from the rock formation being targeted, but the result is the same: the methane and other hydrocarbons are present at increased levels as a consequence of drilling and fracking. There are many well-studied reasons why, and the scale of the problem derives from the scale of widespread drilling.

About 2.6 million onshore oil and gas wells have been drilled in the United States since 1949,[117] and about 1.1 million of these are actively producing.[118] More than 20 years ago, the EPA estimated that about 200,000 of the over 1 million abandoned oil and gas wells in the country were inadequately plugged, meaning that they provide pathways for hydrocarbon gases, if not other fluids, to flow up to the surface or to underground sources of drinking water.[119]

Additionally, over 30,000 wells have been drilled for the purpose of disposing of oil and gas industry wastes, via injection.[120] A gray area lies in how the industry takes brines brought to the surface and then pumps them back underground into wells to improve the flow of oil out of adjacent wells; there are more than 110,000 of these injection wells for "enhanced oil recovery."[121]

Constructed of concrete and steel, all of the above wells age and degrade over time.[122] Moreover, from the beginning of their construction, a significant fraction of oil and gas wells — several percent — have well integrity problems, meaning that injected fluids, hydrocarbons and ancient brines may not be contained within the inner tubing, or casing, of the well.[123] Once outside of this casing, these contaminants give rise to pollution when they escape to the surface or move into underground sources of drinking water that were drilled through in order to construct a well.[124]

Due to a variety of reasons, including cement shrinkage and/or poor bonding, space can form between the outer shell of cement and the various rock formations through which an oil and gas well passes, creating a pathway for the potential flow of contaminants.[125]

A PhD thesis in petroleum engineering, completed in May 2014, explains that highly pressurized fluids during hydraulic fracturing can directly cause such separation, resulting in "underground blowouts" — events in which fracking fluids travel back along the path of the well between the concrete and the rock formation, rather than into the targeted formation.[126] Compared to blowouts that spew fluids into the air at well sites, these blowouts are more difficult to detect, for obvious reasons.[127]

Fluids may also leak from oil and gas wells through small fractures or channels that form within the interior of the constructed well, either within the cement itself or between concentric cylinders of cement and metal pipe, or casing, used to build the well.[128] Improper centering of casings gives rise to less uniform flows of cement during the construction of the well, and this in turn is another factor that increases the risk of well integrity failures.[129] Gradual settling over time due to the extraction of oil and gas also applies stress that may eventually break, or crack, constructed wells, leading to failure.[130]

As the many different mechanisms of well failure suggest, the problem of leaky wells, and outright well failure, is the topic of a large number of studies by industry and academic scientists. The bottom line, however, is that many oil and gas wells leak, and that the causes of leaks are difficult to detect and fix, given that they occur for so many different reasons, subject to diverse geological conditions and to diverse industry practices.

A major concern is that, as a given year's newly drilled and fracked wells decline in production and degrade physically, the percentage that develop integrity problems is likely to increase over time.[131] Yet data on the incidence of well integrity problems as wells age are severely limited, not least because shale gas and tight oil wells are relatively new. A 2003 study looked at federal data on the over 10,000 wells drilled into the outer continental shelf of the Gulf of Mexico at the time, and found that more than 40 percent of those that were over 10 years old displayed "sustained casing pressure," meaning that the wells were not containing hydrocarbon gas within the inner tubing, or casing, used to channel hydrocarbons up for production.[132]

A well head after fracking equipment has been removed from the drilling site.

Now, according to a 2014 study, initial data on shale gas well integrity in Pennsylvania do not bode well for the future.[133] In the Marcellus Shale region of Pennsylvania, shale gas wells have proven to be more prone to well construction "impairments" linked to well integrity problems, compared to conventional wells, especially in the northeastern part of the state, where over 9 percent of shale gas wells have indications of compromised well integrity.[134]

Contamination of aquifers from methane and other hydrocarbon gases alone warrants precaution over widespread drilling and fracking. However, another major concern is that "evidence of stray gas contamination could be indicative of future water quality degradation, similar to that observed in some conventional oil and gas fields."[135] One reason is that such contamination could be a harbinger of contamination from the migration of other fluids, not just the relatively buoyant hydrocarbon gases.[136]

Hydrocarbon gases in aquifers as a sign of more problems to come

If oil and gas companies drill and frack the hundreds of thousands of new shale gas and tight oil wells envisioned, the legacy of aging, degrading and increasingly compromised wells will grow substantially. This legacy may lead to long-term, region-wide changes in how fluids mix and move underground over the coming years and decades. How these changes might impact the quality of underground sources of drinking water remains unknown, highlighting the enormous risks inherent to widespread drilling and fracking.

Aquifers are immediately put at risk when the leading edge of injected fracking fluid propagates new fractures farther than anticipated, reaching nearby oil and gas wells, or injection wells that have compromised cementing and casing.[137] These "frack hits," or so-called well-to-well communication events, sometimes give rise to surface spills,[138] and they are occurring for at least two reasons. First, predicting the actual length of fractures is a notoriously difficult mathematical problem, sensitive to parameters that are specific to the geology surrounding each individual well, and this sensitivity leads to some fractures propagating farther than expected.[139] Second, the locations and depths of many thousands of the more than 1 million abandoned oil and gas wells in the United States are not known.[140]

The issue of frack hits is foreshadowed in regulations set forth by the EPA under the Safe Drinking Water Act, and exposes a complicated story about the oil and gas industry's capture of U.S. regulatory policy. (See Box 4, page 11.)

In addition to the immediate risks of contamination from frack hits, the incidents clearly illustrate how widespread drilling and fracking can change the connectivity of a network of contamination pathways on a regional scale. Several recent studies have begun to approach the larger concerns about long-term impacts on a regional scale, highlighting the severely limited scientific understanding of the issue, and underscoring the simple-mindedness of the current regulatory approach to oil and gas industry injections. (See Box 4.)

A 2012 study used a simplified mathematical model to explore how preferential pathways for fluid flow, such as faults and natural fractures, can influence the time scale in which injected contaminants might reach underground sources of drinking water under a worst-case scenario.[163] The model suggested that slow contamination could occur within a decade.[164] A second 2012 study found evidence of a match between the geochemical profile of salinity in shallow groundwater in northeast Pennsylvania and that of Marcellus brine, suggesting a "preexisting network" of pathways (i.e., unrelated to fracking) between the Marcellus Shale and shallow groundwater.[165] In 2014, another study demonstrated a way to reduce the complexity of modeling the slow flow of contaminants through natural faults,[166] with an aim

Box 4 • *Oil and gas industry injections*

Fluid awaits injection at a fracking site.

Under authority from the Safe Drinking Water Act, the U.S. EPA's Underground Injection Control (UIC) program regulates the oil and gas industry's injections of fluids underground into designated wells (so-called "Class II" wells), but the program only regulates injections of fluids into oil and gas wells for the purpose of hydraulic fracturing if the fracking fluid contains diesel fuel.[141] In 1989, the U.S. Government Accountability Office (GAO) determined that about half of the 27 known or suspected contamination events due to Class II well injections arose because the injected fluids reached underground sources of drinking water via nearby abandoned wells that had integrity problems.[142] These were frack hits, without the fractures.

The exemption for fracking fluids without diesel is known as the Halliburton Loophole, since it was created through legislation crafted behind closed doors, and ushered into law, with heavy influence from former U.S. vice president and former Halliburton CEO Dick Cheney.[143] Halliburton was the first company to conduct hydraulic fracturing operations, in 1949.[144]

Under UIC regulations, new Class II wells are subject to regulations that would require addressing the issue of frack hits, were it not for this loophole.[145] The loophole thus explains how the issue of frack hits has remained beyond regulation, and highlights how the oil and gas industry, through its capture of U.S. energy policy, has erected barriers to protecting public health and the environment.

Regardless, the protections that would be afforded under the Safe Drinking Water Act are severely limited. An Area of Review (AoR) is defined at the surface, surrounding the site of a proposed UIC Class II well, and then if nearby wells or other potential contamination pathways are within (or, more precisely, beneath) this region, basic regulatory safeguards are triggered.[146] The U.S. Code of Federal Regulations provides two options for defining an AoR, the simplest option being to just use a circle with a 400 metre radius.[147] Alternatively, applicants for permits can use a calculation based on simplistic assumptions about the potential flow of the fluids that would be injected to arrive at an AoR.[148] In particular, the basis for the formula is that the formation receiving the injected fluids is "homogenous," meaning that there are no preferential pathways for flow, such as natural fractures and faults.[149]

In 2004, a panel of experts convened by the EPA noted that these options were "adopted even though much existing evidence showed that the actual pressure influence of any authorized underground injection operation is not limited to any predetermined fixed radius around any proposed or existing injection well, but is a function of specific physical parameters (including initial pore pressures in both the injection zone and the lowermost [underground source of drinking water] and actual injection rate)."[150] The panel of experts further emphasized that "a fixed radius AoR is based on operational assumptions made in the early 1980s,"[151] and concluded that "enough evidence exists to challenge the assumption that a fixed radius AoR is sufficient to assure adequate protection of [underground sources of drinking water]... ."[152]

The EPA, despite these strong statements, has kept the simplistic protections in place, having deferred action because state regulatory agencies and the Ground Water Protection Council (GWPC) disagreed with the panel of experts that data show that the 400 meter approach is inadequate.[153] But this decision reflects embedded conflicts of interest.

Most of these state agencies, as regulators of oil and gas development in their respective states, are party to the Interstate Oil and Gas Compact Commission (IOGCC) and thus share in the problematic but culturally entrenched mission of promoting the efficient extraction of oil and gas,[154] so as to prevent "physical waste of oil or gas or loss in the ultimate recovery thereof."[155] The GWPC has been an outspoken advocate of hydraulic fracturing, most notably through its co-sponsorship, with the IOGCC and the oil and gas industry, of the fracking chemical disclosure website, FracFocus.org, which has created a platform for the oil and gas industry that gives the illusion of transparency.[156]

This episode illustrates how longstanding alignments between the oil and gas industry and state governments shape the science on which oversight of the oil and gas industry depends. Current policy that is intended to protect underground sources of drinking water from oil and gas industry injections is based entirely on either an unscientific

(continued on page 12)

("Oil and gas industry injections" continued from page 11)

compromise between the industry and regulators (e.g., the fixed-radius, one-quarter mile AoR approach) or, alternatively, on an overly simplistic calculation using a decades-old mathematical formula that is divorced from modern geological understanding and modern computational science.

With wells now tunneling horizontally more than three kilometers through rock formations and being hydraulically fractured in tens of stages, and with hundreds of millions of liters of fracking fluid — with or without diesel — injected at each stage, much has changed since the "operational assumptions made in the 1980s" that led to the AoR criteria. Yet fracking injections that do not contain diesel fuels are not even afforded the simplistic and dated protections of the standard AoR approach, thanks to the Halliburton Loophole, and until recently fracking injections that do involve diesel fuels have been in regulatory limbo. Complicating matters, disclosure of whether or not companies are using diesel fuels in fracking fluids is predictably problematic. The Environmental Integrity Project revealed that many companies had edited their previous submissions to FracFocus.org, thereby rewriting history and concealing their use of diesel fuels in fracking fluids.[157]

In early 2014, the EPA did finally issue "guidance" for injections of fracking fluid containing diesel fuels.[158] While the guidance acknowledges that the simplistic assumptions for the formula approach do not apply, it merely recommends that regulators use one of several variations on the quarter-mile fixed-radius approach.[159] The guidance is most remarkable in that it still does not draw on decades of progress in the mathematical and computational sciences, emphasizing only that such modeling "often requires a significant body of data."[160] Moreover, the guidance does not mention the modeling efforts that the EPA has commissioned as part of its ongoing study of contamination pathways related to hydraulic fracturing.

In June 2014, in unspoken disapproval of the EPA's guidance on diesel fuels, a GAO report pointed to "new" risks to underground sources of drinking water presented by hydraulic fracturing with diesel fuels and urged the EPA UIC program to convene a panel of experts to review the risks.[161] The report also notes that the surge in the volume and frequency of the oil and gas industry's fluid injections are "overpressurizing" rock formations, leading to surface spills[162] — events that are akin to the surface spills from frack hits.

toward modeling that approaches a regional scale.[167] This effort to incorporate numerous wells and faults at a regional scale is preliminary, based on simplifying assumptions about the geometry and parameters that control flow through these contamination pathways.[168]

The EPA, as part of its multi-year study of the potential impacts of hydraulic fracturing on drinking water resources, has contracted researchers to model a handful of simplistic contamination scenarios.[169] However, the preliminary models are far from being employed to predict and potentially reduce the likelihood of future contamination events stemming from a single fracked well, much less to address the prospect of contamination on a regional scale that communities with widespread drilling and fracking may face.[170]

At the same time, the oil and gas industry's capture of U.S. energy policy is also on display in the results of the contracted research. The scientists modeling the contamination scenarios for the EPA view using their novel computational methods to investigate the likelihood of contamination as somewhat of a side note, and put equal if not greater emphasis on the potential future use of their methods to increase the production of hydrocarbons from hydraulically fractured wells.[171]

The EPA's recent guidance on the use of diesel fuels in fracking fluids merely notes that modeling to actually calculate the potential extent of the migration of injected fluids "often requires a significant body of data."[172] This statement is a reference to the fact that actually determining when and where contamination events are likely to occur requires detailed information that is specific to the geology surrounding individual wells across a region, including the presence of nearby natural faults and fractures, induced fractures from fracking, and compromised wells. Yet this information is not always available.

Actually determining when and where contamination events are likely to occur would also require knowledge of the parameters that control flow through these potentially connected pathways, over long periods of time. These parameters are highly uncertain, and vary by location. Yet the outputs of the models are likely sensitive to the parameters used, and to the assumptions that these parameters embody. For example, assuming that there is no natural fault providing a potential pathway for contamination, when in fact there is one, fundamentally changes the model. The result is that crucial information to ensure protection is not available.

As one federal scientist told journalists at *ProPublica*, "[t]here is no certainty at all in any of this ... You have changed the system with pressure and temperature and fracturing, so you don't know how it will behave."[173] The uncertainty over how the hydrogeological system will respond raises the specter of long-term aquifer contamination as a ticking time bomb, with grave implications for water availability, and for local economies, across the country. This risk is simply unacceptable.

Earthquakes, Lightning Strikes and Exploding Trains

Scientists now believe that, by pumping large amounts of fluids underground, the oil and gas industry is largely to blame for the significantly increased frequency of earthquakes observed in the United States in recent years.[174] For decades, the central and eastern United States consistently registered about 20 magnitude 3.0 or greater earthquakes per year. [175] In the mid-2000s, this trend broke, and earthquake frequency increased, directly coinciding with the expansion of modern drilling and fracking.[176] In 2010, 2011 and 2012 combined, there were about 300 earthquakes of magnitude 3.0 or greater.[177] In just the first half of 2014, Oklahoma alone registered about 200 magnitude 3.0 or greater earthquakes.[178]

In a handful of cases, the evidence suggests that the specific process of hydraulic fracturing has also induced earthquakes, most recently in Ohio.[179] Most of the oil and gas industry earthquakes, however, are evidently occurring when high-volume wastes that are injected into UIC Class II wells lubricate faults, or increase pressure beyond the strength of intersecting faults.[180] A 2014 study has reported evidence that injection of oil and gas industry wastes is triggering earthquakes centered up to over 20 miles away from the injection well, in part because of "modern, very high-rate injection wells."[181]

A magnitude 4.7 earthquake was among the swarm of 1,000 smaller earthquakes all measured in Greenbrier, Arkansas, in 2010 and 2011, again attributed to injections of wastes.[182] Among the oil and gas industry earthquakes that have shaken Oklahoma, none was larger than the magnitude 5.7 earthquake in 2011 that struck Prague, Oklahoma, resulting in injuries to two people and the destruction of 14 homes.[183] Now, a 2013 study has suggested that large remote earthquakes — far from the United States — may actually be triggering earthquakes within the United States, including the magnitude 5.7 earthquake that hit Prague, Oklahoma.[184] That is, oil and gas industry injections appear to be bringing

Residential damage from the magnitude 5.7 earthquake in 2011 that struck Prague, Oklahoma. PHOTO BY U.S. GEOLOGICAL SURVEY

faults to near-critical thresholds, and then seismic waves from large but remote earthquakes can then trigger the movement of these faults.[185]

Identifying when and where critical thresholds are nearly reached requires monitoring that can only be done remotely, and thus imprecisely, given that faults are buried deep underground. This phenomenon of critical thresholds being remotely triggered emphasizes the large uncertainties that cloud the question of when and where the next oil and gas industry earthquake will strike. Just how strong and potentially destructive and costly the industry's earthquakes might become also remains an open question.

In some cases, the fluids injected by the oil and gas industry have evidently entered and activated previously unknown faults.[186] The fact that there are unknown faults further highlights fundamental limitations to understanding, and predicting, when and where the next oil and gas industry earthquake will occur. This fact likewise highlights that assumptions about the network of water contamination pathways within a neighborhood of a given injection well can change.

More generally, the seismic waves that make up earthquakes — whether unleashed naturally or induced by the oil and gas industry's injections — may exacerbate the problem of leaky oil and gas industry wells. The seismic waves pass through at different depths at different speeds, owing to differences in the density (and elasticity) of the underlying layers of rock formations penetrated by an oil and gas well. As a consequence, seismic waves do not uniformly shake the constructed wells, resulting in physical stresses that can only increase the likelihood of cementing or casing failures.

Oil and gas industry earthquakes have taken many by surprise, but scientists have long known that injections (and withdrawals) of fluids beneath the surface can induce earthquakes.[187] Few, if anyone, however, anticipated the recent incidents in North Dakota in which tanks holding oil and gas industry wastes have been struck by lightning, resulting in explosions that spilled contaminants onto surrounding lands and burned for days.[188] The storage tanks are evidently exploding because, in an effort to avoid corrosion, the metal tanks are lined with fiberglass, which has much lower conductivity than metal and thus overheats.[189]

Trains carrying tight oil from drilling and fracking in the Bakken region of North Dakota are also exploding.[190] The surge in tight oil production in North Dakota and Texas has led to a rapid expansion in the transport of oil by train to refineries, in part because production has outpaced pipeline construction.[191] Energy Secretary Ernest Moniz has noted that the oil industry has actually begun to prefer transporting oil by train, for the flexibility it offers.[192] However, several oil train explosions — most catastrophically in Lac-Mégantic, Quebec, which destroyed several blocks of the town and killed 47 people — have brought the so-called bomb trains to the forefront of public attention.[193]

The four high-profile explosions thus far — in Quebec, Virginia, Alabama and North Dakota — reflect that the oil contains relatively large amounts of natural gas liquids, which are highly explosive.[194] The explosions also reflect that large quantities — often more than 10 million liters per train — are now being sent very long distances by rail to refineries, typically about 1600 kilometers.[195]

Aftermath of the Lac-Mégantic, Quebec, oil train derailment in July 2013. PHOTO CC-BY-SA © SÛRETÉ DU QUÉBEC

The oil train explosions have brought the issue of fracking to regions that are not actively targeted for fracking, including Minnesota, Washington, D.C., Alabama and the Pacific Northwest.[196] For example, about 250 oil train cars pass though downtown Seattle each day, and recently several of these cars derailed at low speed, without incident, serving as a potential wake-up call for the city.[197] An analysis of planned projects for expanding refinery capacity in the region — ironically including the conversion of facilities intended for renewable liquid fuels — would add as many as 12 one and a half-kilometer-long oil trains each day to the Northwest railway system.[198]

Taken together, the earthquakes, lightning strikes and exploding trains are a reminder that widespread drilling and fracking now means many different things to the communities that are affected in different ways. But nothing affects residents of these communities living alongside oil and gas industry sites more viscerally than the oil and gas industry's air pollution, which flows along with the industry's climate pollution.

Air and Climate Impacts

In essence, drilling and fracking gives rise to three different streams of pollutants flowing into the air: the clouds of silica dust from mining for and managing the sand used in fracking fluids; the plumes of combustion byproducts from engines, flares and explosions; and the stream of pollutants that the oil and gas industry both brings to the surface and leaks into the air.

Compromises with the industry call for more monitoring to better understand precisely what the risks of toxic exposures are for everyone living alongside drilling and fracking operations, but calls for prolonged monitoring and more studies just guarantee further pollution, and further harm. Even assuming that strong regulation and oversight can be put in place, and that negligence, accidents and explosions can be eliminated, the baseline level of the industry's air and climate pollution will guarantee certain harm to public health and will lock in unacceptable climate risks. The industry's air and climate pollution is best avoided altogether with a ban on fracking.

Silica dust

Clouds of silica dust form at well sites as sand is managed and prepared for mixing into fracking fluid.[199] Silica dust clouds also emanate from silica mining and processing

PHOTO CC-BY-SA © FRED AUCH / FRACTRACKER.ORG

sites. As with the issue of exploding oil trains, silica sand mining has broadened the reach of fracking's impacts beyond regions targeted for shale gas and tight oil extraction, with large amounts of silica mined from or processed in Wisconsin, Minnesota, Illinois and Iowa.[200]

A recent review of the public health impacts of drilling and fracking summarizes that "[r]espirable silica can cause silicosis and lung cancer and has been associated with tuberculosis, chronic obstructive pulmonary disease, kidney disease, and autoimmune disease."[201] The National Institute of Occupational Safety and Health measured silica levels at 11 well sites, as silica sand was being managed, and found that exposures exceeded thresholds set to protect worker health, in some cases by a factor of 10.[202]

Residents living nearby operations may also face serious health risks. "The breathing part of it isn't good. You can just feel it in your throat, feel it in your nose," explained an individual living across the street from a Wisconsin sand-washing plant.[203] But the specific consequences for those living nearby sand mines and drilling sites remain unknown, and largely unstudied.[204] A school in New Auburn, Wisconsin, situated near four silica sand mines, has found silica on air filters used in the school's air system, suggesting that low-level exposure in the community may be the norm.[205]

Byproducts from combustion

Exhaust from the diesel generators and large trucks that crowd well sites, and smoke from flaring at well sites, processing plants, and compressor stations, not to mention explosions, create a second stream of toxic air emissions.

Along with carbon dioxide from combustion, these plumes contain variable amounts of hazardous air pollutants, including nitrogen dioxides, carbon monoxide, particulate matter, and volatile organic compounds (VOCs), such as the hydrocarbons benzene, toluene, ethylbenzene and xylenes (BTEX) and various polycyclic aromatic hydrocarbons (PAHs).[206]

Hundreds of heavy-duty truck trips per well are required, largely to transport water, chemicals, and equipment, as well as the wastes that result from drilling and fracking.[207] Getting the industry to convert to fleets of trucks and generators that burn natural gas would lessen the air quality problems from diesel exhaust, and the respiratory and cardiovascular health problems associated with such exhaust,[208] but not without the ill effect of locking in demand for more drilling and fracking.

Smoke from flares at well sites and processing plants adds to the baseline levels of engine exhaust in much less-defined ways, dependent on the efficiency of combustion and the makeup of the waste gases being burned. Of course individual explosions are unforeseen, but they have become an expected consequence of business as usual, and they can lead to toxic smoke billowing for days.[209]

The pollutants that oil and gas companies bring to the surface

The third stream of oil and gas industry pollution forms out of the plumes of well- or site-specific mixes of hydrocarbons and other air and/or climate pollutants, as discussed in Box 2 (page 4). These are the pollutants that come from below ground, and that are mobilized into the air in the aftermath of drilling and fracking. Now, based on a handful of studies in 2013 and 2014, it has become clear that the oil and gas industry emits more air and climate pollutants than officials estimate.

The air and climate pollutants that oil and gas companies bring to the surface include: methane and other VOCs, such as the BTEX hydrocarbons and other "aromatic" hydrocarbons, including PAHs; hydrogen sulfide; radon derived from radium present in targeted rock formations; and any chemicals from fracking suspended in the air as vapor or aerosol, such as glutaraldehyde, ethylene glycol and methanol.[210]

Varying amounts of these pollutants flow from a vast array of sources at successive stages within the industry, including: during drilling, cementing and casing; immediately after fracking fluid injection; from stored wastes; from any accidents, spills and explosions; and from inefficient flares and leaky valves, flanges, seals, pneumatic devices, pipes and other equipment used to manage, process, compress and transport the payoff hydrocarbons — the crude oil, natural gas liquids and natural gas.[211]

Again, methane is a potent greenhouse gas and a primary driver of global warming.[212] The BTEX air toxics irritate skin and can cause respiratory and nervous system problems with short-term exposure, and can cause greater harm with long-term exposure, including cancer.[213] In the presence of sunlight, BTEX and other VOCs also combine with combustion byproducts to form ozone, a respiratory irritant that can prove fatal for those with asthma.[214] PAHs that fall on land and surface waters can accumulate in the food chain, potentially resulting in harmful levels of exposure for humans who consume contaminated fish.[215] Hydrogen sulfide is highly poisonous, and oil and gas industry workers at well sites may be advised to wear personal monitors equipped with alarms.[216]

The chemicals in fracking fluid, as well as largely unknown byproducts of chemical reactions during fracking, are mobilized along with hydrocarbon gases and other pollutants, and emitted into the air to varying degrees.[217] This puts the issue of fracking chemical disclosure into proper perspective as a significant but nonetheless singular component of the industry's pollution. Full chemical disclosure would not put an end to the industry's water and air pollution.

The issue of fracking chemical secrecy nonetheless resonates with the public, in part because it is an example of the deference that policymakers regularly grant to oil and gas companies, and because it illustrates how such deference holds back scientific investigations of the industry's impacts on public health and the environment. Indeed, some in the oil and gas industry have worked with the American Legislative Exchange Commission (ALEC), and ALEC has in turn helped to see that state legislatures only consider disclosure requirements that are acceptable to the industry.[218] Even when disclosure is required in the event of emergencies, as is the case in some states, a company can be slow to comply.[219]

While regulations vary by state, trade-secret protections granted in the Toxic Substances Control Act mean that fracking companies typically do not have to disclose all the chemicals they pump underground.[220] In fact, in many cases, oil and gas companies fold off-the-shelf products into the fracking fluids that they make on-site, without actually knowing the chemicals contained in these products.[221]

It is known that oil and gas companies have injected a wide variety of toxic chemicals to fracture wells, and have injected many more chemicals for which toxicities are not well studied.[222] For example, among the chemicals identified, over 100 are known or suspected endocrine disruptors.[223] Numerous known or suspected carcinogens also have been used since 2005 as additives in hydraulic fracturing fluids.[224] Many of the known chemicals used are volatile, meaning that they escape readily into the air.[225] Very little is known about health risks posed by mixtures of all the chemicals brought to the surface, and the extent of chemical reactions that form dangerous byproducts.[226]

Emissions are larger than officials estimate

Beyond inadequate requirements for disclosure of fracking chemicals, there are many other fundamental challenges to quantifying the oil and gas industry's releases for each of the above pollutants.

The challenges begin with the number and diversity of sources, and how the constellation of sources changes over time as the oil and gas industry operates, targets new areas and adopts new practices.[227] Geological differences from well to well, and different stages within the oil and gas system — from production to distribution — give rise to differences in the chemical compositions of what gets released into the air.[228] The flow rate and chemical composition of the plumes from a single source can also change over time, under normal operations,[229] and can increase quickly, and unexpectedly, as a consequence of equipment failures.

These factors make the size and chemical compositions of the plumes in the third stream of emissions variable, or well- and site-specific. Importantly, understanding of the industry's emissions is blocked by lack of access to sites and to data held by oil and gas companies, presuming that they have data. As noted already, these companies are empowered by trade-secret protections and by key exemptions granted to the oil and gas industry under the landmark environmental laws. A PhD thesis completed in 2014 reveals another obstacle to full information: sources not counted at all, such as abandoned oil and gas wells leaking methane and other hydrocarbon gases.[230]

Against these challenges, the EPA estimates emissions using a bottom-up approach, beginning with an inventory of all of the different industry activities undertaken in a given year.[231] The EPA then uses largely dated estimates of average emissions of each activity to arrive at an estimate of total emissions from the oil and natural gas systems.[232] This approach relies heavily on voluntary self-reporting from the industry.[233]

In 2013, the EPA Inspector General found many oil and gas industry emission factors to be of "low or unknown quality" due to insufficient data, leading to a result that "likely underestimates actual criteria pollutant emissions from oil and gas production sources."[234] For example, there are no emission factors for air toxics and VOCs emanating from waste pits, from produced water tanks, from steps in the well completion process including the specific process of fracking, and from pneumatic devices, or pressure valves.[235]

Data on the actual levels of various hydrocarbons in the atmosphere, taken from aircraft flights and/or from surface monitoring locations, make possible an alternative, top-down approach to estimating industry emissions. Using atmospheric chemistry, scientists take these data and then combine them with data on wind patterns to estimate, working backward, what the dynamic streams of methane and other hydrocarbons were that flowed together over an oil and gas play and gave rise to the hydrocarbon levels that were measured.[236]

Scientists using this aircraft measurement approach in Utah, Colorado and Pennsylvania suggest that much more methane and other air pollutants are flowing from oil and gas sites than bottom-up estimates based on dated emission factors and industry self-reporting.[237]

Flying over an oil and gas field in Utah one day in February 2012, Karion et al. measured very large levels of methane — the equivalent of between 6.2 percent and 11.7 percent of natural gas production that month, assuming that the day was representative of daily emissions that month.[238] In April 2014, Caulton et al. published a study of methane emissions during the drilling stage at well sites in Pennsylvania and found several super-emitters, each releasing 100 to 1,000 times the EPA's estimate of emissions during the drilling phase, as utilized in its bottom-up, inventory estimates.[239] In May 2014, Pétron et al. looked at methane emissions in the Denver-Julesberg basin in Colorado over a two-day stretch in 2012 using monitoring equipment on towers and on aircraft flown above the play, and concluded from the measurements that methane emissions

were "close to 3 times higher than an hourly emission estimate based on EPA's Greenhouse Gas Reporting Program data for 2012."[240]

Because of variability from site to site, methane emissions can be used only as a crude indicator of emissions of other pollutants brought to the surface by the oil and gas industry. Nonetheless, these results are consistent with the EPA Inspector General's conclusion that current inventory estimates understate the oil and gas industry emissions of air toxics and other VOCs, not just methane.

Importantly, Pétron et al. estimated that benzene emissions were about seven times larger than the Colorado inventory estimates would suggest.[241] The fact that benzene emissions were evidently not just approximately three times larger, consistent with the finding on methane emissions, but closer to seven times larger, shows how simple, generic (i.e., linear) formulas for inferring non-methane VOC levels from methane levels can mislead. Simple inference of non-methane VOCs from methane can hide potentially crucial — and harmful — differences in the compositions of the raw hydrocarbon gases from well sites, as well as hide differences in the compositions of the different streams of natural gases managed at different stages in the natural gas system. In other words, far more harmful gases than have been estimated may be flowing from some wells in some regions, not just from the Denver-Julesberg basin. This highlights that widespread drilling and fracking is a large, uncontrolled experiment, and that the consequences for human health remain largely unknown.[242]

Top-down studies based on aircraft measurements only provide a look at emissions over a short time span, and from sources within relatively small areas of industry activity. A paper published in December 2013 by Miller

et al. has suggested that, nationally, in 2010, leakage of natural gas from the oil and gas industry in the United States amounted to the equivalent of over 3 percent of end-use natural gas consumption that year; that is, the authors suggested that actual emissions were more than 30 percent higher than the EPA's estimate at the time.[243] In a review published in February 2014, Brandt et al. surveyed the scientific literature on oil and gas industry methane emissions and likewise concluded that the bottom-up, inventory approach used by the EPA significantly underestimates national methane emissions.[244]

Natural gas dependence causes more global warming than thought

Because understanding of national methane emissions is lacking, the climate impacts of widespread drilling and fracking are a matter of current debate.[245] But the overwhelming focus of this debate on the climate impacts of using natural gas instead of coal to generate electricity loses sight of the oil and gas industry's role as a major source of climate pollution.

About two thirds of U.S. climate pollution stems from the oil and gas industry, with a little under 30 percent stemming from natural gas production, processing, transport and use.[246] However, the estimates of methane leakage used to arrive at these figures are based on the official underestimates discussed above.[247] The above figures on climate pollution stemming from the oil and gas industry also hinge on comparisons of the relative contributions of the different greenhouse gases to global warming.[248] Now, according to the consensus science that is presented in the most recent Intergovernmental Panel on Climate Change (IPCC) assessment, it is clear that officials have also been greatly underestimating the potency of methane as an agent of climate change.[249]

The IPCC now states that, pound for pound, a pulse of methane from the oil and gas industry traps 36 times more heat than a pulse of carbon dioxide, over a 100-year time frame, and traps 87 times more heat over a 20-year time frame.[250] Remarkably, since the first IPCC assessment report, each subsequent report — in 1996, 2001, 2007 and most recently 2013 — has increased the estimate of methane's "global warming potential," relative to carbon dioxide.[251] The most recent increase was the largest,[252] raising the question of whether more increases are in store as climate science progresses.

Notwithstanding the significant climate pollution from the natural gas system, advocates of natural gas have touted the fuel as a tool for addressing the challenge of global warming.[253] Debate over the climate impacts of switching to natural gas from other fossil fuels has become controversial, in part because it is based on a false choice: burn natural gas or burn other fossil fuels. Framing the climate impact of fracking in this way loses sight of three crucial points.

First, most recently, fracking is being done primarily to extract oil. Since the end of August 2012, about 75 percent or more of drilling rigs have targeted primarily oil, not natural gas, and about two thirds of all the drilling rigs operating in the United States are the sort capable of drilling horizontally through shale and tight rock formations.[254] Fracking makes it possible to bring to the surface and burn much more oil than previously imagined, and there has never been any pretense that such oil consumption is anything but bad for the climate.[255] Second, increased natural gas use in the electricity sector does not just displace other fossil fuels, it displaces cleaner solutions, such as solar, wind and efficiency.[256] Third, much of the coal displaced, instead of staying underground, is just being exported and burned in other countries, offsetting, at an international level, the U.S. reductions in carbon dioxide emissions that come from switching to natural gas.[257] The claim that these other countries would just burn coal from elsewhere anyway[258] reflects the exceptionally low standards for U.S. leadership on the issue of global warming.

These three caveats set aside, Food & Water Europe took a close look at the conditions and assumptions under which using natural gas instead of other fossil fuels might actually mean marginally less global warming. Burning natural gas does produce about half as much carbon dioxide as burning coal, with less potential for carbon dioxide reductions when using natural gas instead of heating oil, gasoline or diesel.[259] However, these potential carbon dioxide reductions are offset by the leakage of methane from the natural gas system, and just how much they are offset remains an open and controversial question.[260]

There are a variety of ways to compare methane emissions to carbon dioxide emissions, in order to begin to quantify the climate impacts of burning natural gas instead of coal, or heating oils, or gasoline or diesel.[261] Methane does not persist in the atmosphere for as long as carbon dioxide, so metrics used to compare emissions of the two greenhouse gases depend on the time frame considered.[262] Focusing on the next few decades, a time frame in which methane traps much more heat than carbon dioxide does, pound for pound,[263] is necessary for three fundamental and pressing reasons.[264]

The first reason is that we face the risk that climate tipping points will be surpassed in the near term, meaning that natural positive feedbacks could kick in and lead to irreversible changes.[265] For example, reduced Arctic ice coverage means more absorbed sunlight and warming.[266] Further, any warming that thaws ice crystals that had trapped methane will give rise to more methane emissions, and thus more warming.[267] Indeed, thawing of permafrost in the Yamal Peninsula in Russia, and the subsequent release of massive amounts of methane, likely explains the formation of seemingly bottomless craters in July 2014.[268] Second, even discounting the risk of climate tipping points, the changes to the climate that are already expected to accompany 2 degrees Celsius of post-industrial warming promise to be dangerous and costly.[269] Third, current climate science warns that to have a "good" chance — that is, significantly better than a 50-50 chance — of keeping warming from going beyond 2 degrees Celsius requires a very rapid transition off of all fossil fuels, leaving most underground.[270]

Returning to the question of methane leakage, a 2012 study found that natural gas leakage that amounts to more than about 3.8 percent of natural gas consumption means that switching from burning coal to burning natural gas to generate electricity would be worse for the climate for about 20 years, a wash at 20 years, and marginally less damaging thereafter.[271] The authors further determined that leakage at about 7.6 percent would make such a switch worse over a 100-year horizon.[272] These breakeven leakage rates were calculated, however, using the now outdated estimates of methane's potency as a driver of climate change.[273]

Now, looking over the 20-year horizon, the breakeven leakage rate is closer to 2.8 percent for electricity generation, when accounting fully for the new IPCC estimates of methane's potency.[274] Similarly, on the 20-year time frame, the breakeven leakage rates are also lower, now at about 0.9 percent when natural gas displaces diesel in heavy trucks and 1.7 percent when natural gas displaces gasoline in cars, although both of these breakeven leakage rates do not incorporate several factors that would make them even lower.[275] As stated already, natural gas leakage in 2010 amounted to more than 3 percent of consumption in 2010.[276] It remains to be seen how much more natural gas than 3 percent leaked then, and whether much more than 3 percent continues to leak.[277]

Therefore, at best, it will take decades before switching from coal to natural gas in the electricity sector will translate to moderately less climate damage — that is the reality of the "climate benefit" presented by advocates of drilling and fracking for natural gas. Crucially, this presumes that strong regulatory and enforcement regimes can be put in place to reduce leakage; yet given the entrenched position that the oil and gas industry enjoys in American politics, economics and law, such a regime remains unlikely.

Several studies have already made clear that simply shifting to greater energy dependence on natural gas will do little to change our current path toward devastating impacts from global warming.[278] Yet these studies were completed before the consensus increase in the potency of methane as a greenhouse gas, and they pre-date the evidence that officials have significantly underestimated methane emissions from the oil and gas industry. In particular, the International Energy Agency estimated that a "Golden Age of Gas" scenario of increased global dependence on natural gas would lead to an increase in the global average temperature of 3.5 degrees Celsius by 2035, from pre-industrial times.[279]

PHOTO CC-BY-SA © J. WILLIAMS / FRACTRACKER.ORG

Allowing a 3.5 degrees Celsius increase in global mean temperature is unconscionable.[280] It would change regional growing seasons and alter familiar rainfall and snowmelt patterns, threaten coastal communities and economies with rising and acidifying seas, bring regional droughts that are unprecedented in human history, and risk climate tipping points, including "abrupt and irreversible" changes in ecosystems, with runaway warming fueled by positive feedbacks in the climate system.[281]

Clearly, we must urgently bring the fossil fuel era to an end. As corollary, we must keep those with large stakes in oil and gas extraction from sinking capital and labor into infrastructure that would lock in decades more climate pollution.[282] Yet that is precisely the outcome that we can expect if we follow the current course of U.S. energy policy, marked by long-term commitments to increased natural gas-fired electricity generation[283] and to sinking tens of billions of dollars, if not hundreds of billions of dollars, into a massive build-out of fossil fuel export infrastructure.[284]

Illustrating the hypocrisy of the oil and gas industry's rhetoric regarding fracking and U.S. energy security, current applications for authorization to export liquefied natural gas amount to a staggering 60 percent of 2013 U.S. dry natural gas production.[285] Because conventional production of natural gas is in decline, increases in demand for natural gas to fulfill export contracts would lead to intensified and accelerated drilling and fracking for shale gas.[286]

Public Health, Economic and Social Impacts

All of the above threats from drilling and fracking are negatively affecting quality of life in impacted communities, and bringing harm to public health and to local economies. Health problems and other injuries stemming from drilling and fracking operations have turned upside down the lives of many hundreds if not thousands of affected individuals.[287] These harms are compounded by the larger public health and economic problems that communities face due to the oil and gas industry's climate pollution and the ticking time bomb scenario of looming, long-term risks to vital aquifers.

Regarding the specific public health impacts from air pollution, one key 2014 study explains how the "episodic and fluctuating" nature of the toxic plumes of pollutants from industry sites means that standard air quality measures — which average over a region, and average over stretches of time — can miss the "intensity, frequency or durations of the actual human exposures to the mixtures of toxic materials released regularly at [unconventional natural gas development] sites."[288] The authors summarize these health problems as including "respiratory, neurologic, and dermal responses as well as vascular bleeding, abdominal pain, nausea, and vomiting."[289] The authors suggest that the episodic and fluctuating nature of the industry's pollution explains the current disconnect between the many reports of health problems, on the one hand, and on the other hand the contrary claims of minimal air quality impacts, based on air quality measures that smooth out, and thus fail to see, the actual peak exposures experienced by individuals.[290]

One unfortunate aspect of the cases of health problems that have accumulated in Pennsylvania is that state health officials may have been under directions to look the other way,[291] serving as a sad reminder of the very real consequences that flow from corporate capture of regulatory processes that are intended to protect the public.

In Colorado, air quality measurements revealed that residents living closer to oil and natural gas wells were shown to have a higher risk of exposure to cancer-causing benzene.[292] Some of the same scientists, in a subsequent study published in 2014, showed an association between birth defects and the proximity and number of oil and gas wells to each new mother's home address during pregnancy.[293]

In several regions of the United States, ozone — which damages crops and exacerbates breathing problems, among other health problems — has reached harmful levels owing in large part to the collective sources of VOCs and combustion byproducts emitted from oil and gas operations.[294]

An expansive and adaptive network of real-time monitors of air pollution emissions would be required — coupled with full chemical disclosure, and full understanding of the byproducts of fracking chemical reactions — before the full extent of the exposures experienced by industry workers and by those living nearby can actually be known. This would involve a large, expensive, regulatory effort, but open research questions would continue to persist regarding the health effects of combined exposures.[295]

Researchers working under Maryland Governor Martin O'Malley's "Marcellus Shale Safe Drilling Initiative" have made explicit that the best data would be generated if Maryland residents who are unfortunate enough to live or work alongside drilling and fracking sites could wear personal air quality monitoring devices.[296] This illustrates vividly that these residents would be the subjects — human guinea pigs, in fact — of a large uncontrolled experiment addressing these open questions. It is unacceptable that residents of communities targeted with drilling and fracking face being enrolled in this experiment so that oil and gas industry interests can expand drilling and fracking.

Yet beyond the chemical pollutants, there are many other important public health and economic stressors that accompany widespread fracking.[297] In January 2013, the American Public Health Association adopted a policy statement citing "a wide range of potential environmental health concerns" including noise and light pollution and impacts on community wellness and mental health, occupational health, local public health, and health care and emergency response systems.[298]

More broadly, the social and economic disruptions experienced by communities include: diverse physical and mental health consequences[299]; increased demand on emergency and other social services, and damage to public roads[300]; declines in property values[301]; increases in crime and sexually transmitted disease[302]; and losses felt in established sectors of local economies, such as agriculture and tourism.[303] In Pennsylvania, housing shortages are doubling and tripling local rents, forcing lower-income workers who previously had been self-sufficient to turn to public assistance for help covering the higher cost of living.[304]

Importantly, some of the disruptions that communities face are likely to persist long after the oil and gas industry leaves town. A 2014 study focused on community risks reports that "[o]ver the long-term, natural resource dependent communities experience relatively high rates of unemployment and poverty, instability, inequality, crime, and low educational attainment."[305] As one North

Dakota social services director puts it, "about 10 percent of the people are making a profit from the oil wells and 90 percent have to put up with the problems."[306] This puts into perspective the industry's claims about jobs, which typically derive from crude, proprietary and unverifiable economic forecasting models, based on data provided by the industry.[307]

For communities subjected to booms followed by busts in natural resource extraction, the explanations for negative outcomes over the long term include: "susceptibility to volatile economic patterns related to mineral development, a lack of wealth captured at the local level, decreased outside investment, a lack of economic diversity, and ineffective governance."[308]

Wealth is not captured at the local level when leaseholders profiting from extraction are not local. Also, when oil and gas companies move in to drill and frack oil or gas in a new region, much of the associated spending happens out of state, where companies are headquartered and skilled workers are based.[309] Decreased investment and "lack of economic diversity" in communities with drilling and fracking may stem in part from the "stigma" created by industrial pollution, and the looming risk of contamination over the long term.[310] Longstanding pillars of local economies can get crowded out during a local boom and fail to recover once drilling activity declines, particularly agriculture and tourism, which typically rely heavily on a community or region's brand.[311]

As for "ineffective governance" at the local level,[312] this is compounded by the oil and gas industry's pervasive, longstanding and outsized influence on state- and federal-level governance. Given the exemptions under all the landmark environmental laws, the federal government has "largely and deliberately cut itself out of the regulatory picture," leading to a "fractured and fragmented regulatory policy nationwide."[313] Different states, and municipalities, have taken different approaches, ranging from outright bans to a "race to the bottom" trying to accommodate the oil and gas industry.[314] Such accommodation comes at the public's expense.

The open scientific questions surrounding the impacts of fracking amount to irreducible and unacceptable risks. Even assuming some ideal form of governance that is not ineffective, the inevitable harm caused by accidents, leaks and spills of pollutants, the long-term of risk of groundwater contamination, the climate pollution, and the social and economic disruption, all taken together, warrant a ban on fracking.

Battling a fracking wastewater liner fire in Hopewell Township, Pennsylvania. PHOTO CC-BY-SA © FRACTRACKER.ORG

Ban Fracking and Usher in a Safe and Sustainable Energy Future

The evidence is clear. All of the above impacts from widespread drilling and fracking create significant public health and environmental risks and harms, and endanger society with the prospect of a wildly unstable climate. Current scientific understanding supports precaution in the face of these risks and harms. Climate science, in particular, supports urgent action to bring an end to our dependence on fossil fuels.[315] Yet on top of all the risks and harms reviewed in this report, widespread fracking is supplanting opportunities to benefit from safe and sustainable energy solutions.[316]

Hundreds of communities across the country, and around the world, are rising to the occasion with municipal bans, calls for moratoria, and other actions against fracking.[317] These actions directly challenge the legitimacy of the oil and gas industry's entrenched position within our politics, economy, infrastructure, institutions, laws and culture. They are signs of the necessary social and moral shift away from fossil fuels.[318] The actions help foster a transition to a safe and sustainable energy system.

Calling on well-heeled lobbyists, political campaign war chests and public relations specialists, the oil and gas industry is, in response, leveraging its entrenched position in politics, society and our economy,[319] but this response will fail.

The United States is blessed with abundant renewable energy resources, and we have innovative technologies and proven policies for eliminating wasteful and needless energy use.[320] We simply require urgent political action, strong political leadership and rapid cultural change to reorient our economy around needing less energy, meeting energy needs efficiently and harnessing renewable energy resources.

Box 5 • *Lessons for Europe*

A fracking boom, as occurred in the US over the last decade, is unlikely to spread across Europe. Limited geological knowledge about Europe's shale and other unconventional resources and a less developed oil & gas industry will slow down efforts to extract shale gas in the European Union.

Yet, some governments in Europe have firmly bought into a hype about the potential of shale gas, promoted by Big Oil & Gas, and, are pursuing 'a dash for gas' approach in an effort to facilitate exploration efforts.

However, early exploration efforts in Poland, the UK and Romania have been heavily contested: Local residents, farmers, water companies, beer brewers and environmental groups have all teamed up to stop fracking, before it gets underway.

There is no public acceptance of fracking in Europe: The growing body of evidence about the negative climate, environmental and public health impacts of fracking in the United States should continue to strengthen the movement to ban fracking, especially in a densely populated continent like Europe.

To usher in this vision for a safe and sustainable energy future — and to fast forward the necessary social and moral shift away from all fossil fuels — we urge communities and local, state and federal policymakers in the US to:

- Ban fracking and ban associated activities, such as sand mining and waste disposal that support fracking;
- Fully investigate claims of contamination from drilling and fracking;
- End the oil and gas industry's exemptions from environmental and public health laws;
- Terminate public funding of the oil and gas industry, including the billions of dollars in direct tax breaks that pad industry profits each year;
- Stop fossil fuel exports and the construction of infrastructure to support these exports;
- Enact aggressive energy conservation policies, including large public transportation investments and widespread deployment of other energy-saving solutions;
- Establish ambitious programs for deploying and incentivizing existing renewable energy and energy efficiency technologies in order to slash fossil fuel demand;
- Modernize the U.S. electrical grid so that it caters to distributed renewable power generation; and
- Make sweeping investments in research and development to overcome technological barriers to the next generation of clean energy and energy efficiency solutions.

PHOTO BY SUSAN WOZNY

Endnotes

1 Food & Water Watch. "U.S. Energy Insecurity: Why Fracking for Oil and Natural Gas Is a False Solution." November 2012 at 6 to 7.

2 Reddall, Braden. "California senators want more information on oil well 'acid jobs'." *Reuters*. June 18, 2013; Allen, Greg. "Florida county goes to court over 'acid fracking' near Everglades." *National Public Radio*. July 2, 2014; American Petroleum Institute (API). [Briefing paper]. "Acidizing: Treatment in Oil and Gas Operators." May 2014 at 1.

3 Brandt, A. R. et al. "Supplementary materials for 'Methane leaks from North American natural gas systems'." *Science*. Vol. 343, Iss. 733. February 14, 2014 at 45; API. [Press release]. "Investment in U.S. shale well drilling surges in 2011." April 29, 2013.

4 "Little oversight for offshore fracking." *Associated Press*. October 19, 2013; Wethe, David. "Deep water fracking next frontier for offshore drilling." *Bloomberg*. August 7, 2014; Halliburton. [White paper]. "Fracturing Fluid Systems." July 2013 at 5.

5 U.S. Energy Information Administration (EIA). "Annual Energy Outlook (AEO) 2012: With Projections to 2035." DOE/EIA-0383(2012). June 25, 2012 at 59.

6 Ingraffea, Anthony R. et al. "Assessment and risk analysis of casing and cement impairment in oil and gas wells in Pennsylvania, 2000–2012." *Proceedings of the National Academy of Sciences*. Preprint, published online May 30, 2014 at 2; Davies, Richard J. et al. "Oil and gas wells and their integrity: Implications for shale and unconventional resource exploitation." *Marine and Petroleum Geology*. Vol. 56. September 2014 at 5.

7 Lawrence, Bridget. Halliburton. "Before abandoning your well, why not consider a re-frac?" April 18, 2013; Brandt, A. R. et al. "Supplementary materials for 'Methane leaks from North American natural gas systems'." 2014 at 46; Hughes, J. David. Post Carbon Institute. "Drill, Baby, Drill: Can Unconventional Fuels Usher in a New Era of Energy Abundance." April 2013 at ii.

8 Gold, Russell and Tom McGinty. "Energy boom puts wells in America's backyards." *Wall Street Journal*. October 25, 2013.

9 *See* Food & Water Watch, Fracking Action Center, Local Actions Against Fracking. Available at www.foodandwaterwatch.org/water/fracking/fracking-action-center/local-action-documents/. Accessed August 23, 2014.

10 Loder, Asjylyn. "Shakeout threatens shale patch as frackers go for broke." *Bloomberg News*. May 27, 2014; Loder, Asjylyn. "Dream of U.S. oil independence slams against shale costs." *Bloomberg News*. February 26, 2014; Barron, Jeff. U.S. EIA. "As cash flow flattens, major energy companies increase debt, sell assets." July 29, 2014.

11 Nelder, Chris. "The energy transition tipping point is here." *SmartPlanet*. March 3, 2014.

12 Fernholz, Tim. "Four reasons why US fracking could turn out to be a bubble." *Quartz*. July 23, 2014; Food & Water Watch. November 2012 at 7 to 12; Stockman, Lorne. Oil Change International. "Should It Stay or Should It Go? The Case Against U.S. Crude Oil Exports." October 2013 at 4 and 11.

13 Campanale, Mark and Jeremy Leggett. Carbon Tracker Initiative. "Unburnable Carbon: Are the world's financial markets carrying a carbon bubble?" July 2011 at 2 and 6; International Energy Agency (IEA). "World Energy Outlook 2012." 2012 at 259; Hansen, James et al. "Assessing 'dangerous climate change': Required reduction of carbon emissions to protect young people, future generations and nature." *PLoS One*. Vol. 8, Iss. 12. December 2013 at 3; Field, Christopher et al. "Technical Summary for Policymakers." In Field, Christopher et al. (2014). *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change: Summary for Policymakers*. New York: Cambridge University Press at 14.

14 Rabe, Barry G. "Shale play politics: The intergovernmental odyssey of American shale governance." *Environmental Science & Technology*. Vol. 48, Iss. 15. August 5, 2014 at 8370.

15 Holeywell, Ryan. "Former Obama official: Fracking has never been an environmental problem." *FuelFix*. February 5, 2014; Diouhy, Jennifer A. "Salazar navigates ethical limits in new role." *FuelFix*. June 11, 2013; *See* Public Accountability Initiative (PAI). "Industry Partner or Industry Puppet? How MIT's influential study of fracking was authored, funded, and released by oil and gas industry insiders." March 2013; *See* PAI. "Fracking and the Revolving Door in Pennsylvania." February 2013; Horn, Steve. "Revealed: Former Energy in Depth spokesman John Krohn now at U.S. EIA promoting fracking." *DeSmogBlog*. May 23, 2014; Horn, Steve. "Heather Zichal, former Obama energy aide, named to board of fracked gas exports giant Cheniere." *DeSmogBlog*. June 20, 2014.

16 *See* PAI. "Contaminated Inquiry: How a University of Texas Fracking Study Led by a Gas Industry Insider Spun the Facts and Misled the Public." July 2012; *See* PAI, March 2013; Horn, Steve. "Frackademia: The people & money behind the EDF methane emissions study." *DeSmogBlog*. September 16, 2013; Horn, Steve. "'Frackademia' strikes again at USC with 'Powering California' study release." *DeSmogBlog*. March 14, 2014.

17 U.S. Environmental Protection Agency (EPA). Office of Inspector General (OIG). "Response to Congressional Inquiry Regarding the EPA's Emergency Order to the Range Resources Gas Drilling Company." Report No. 14-P-0044. December 20, 2013 at 16; Brandt, A. R. et al. "Supplementary materials for 'Methane leaks from North American natural gas systems'." 2014 at 42.

18 U.S. Government Accountability Office (GAO). "Interior Has Begun to Address Hiring and Retention Challenges but Needs to Do More." GAO-14-205. January 2014 at 14.

19 Nolon, J. R. and S. E. Gavin. "Hydrofracking: State preemption, local power, and cooperative governance." *Case Western Reserve Law Review*. Vol. 63, Iss. 4. April 29, 2013 at 1001 to 1013; Mall, Amy and Dianne Donnelly. Natural Resources Defense Council. "Petition for Rulemaking Pursuant to Section 6974(a) of the Resource Conservation and Recovery Act." September 8, 2010 at 8 to 9.

20 Roberts, David. "Direct subsidies to fossil fuels are the tip of the (melting) iceberg." *Grist*. October 27, 2011; Nelder, Chris. "Reframing the transportation debate." *SmartPlanet*. October 19, 2011.

21 Organisation for Economic Co-operation and Development (OECD). (2013). *Inventory of Estimated Budgetary Support and Tax Expenditures for Fossil Fuels 2013*. Paris: OECD Publishing at 429 to 430; Weiss, Daniel. "Obama budget drains tax breaks for Big Oil." *ClimateProgress*. April 10, 2013.

22 Sierra Club and Oil Change International. "Polluting Our Democracy and Our Environment." April 2014 at 2.

23 U.S. EIA. "Glossary: crude oil" Available at www.eia.gov/tools/glossary/. Accessed August 22, 2014.

24 U.S. EIA. "Glossary: natural gas liquids." Available at www.eia.gov/tools/glossary/. Accessed August 22, 2014; von Oettingen, Wolfgang Felix. "The toxicity and potential dangers of aliphatic and aromatic hydrocarbons." *Yale Journal of Biology and Medicine*. Vol. 15, Iss. 2. December 1942 at 167.

25 U.S. EIA. "Glossary: natural gas." Available at www.eia.gov/tools/glossary/. Accessed August 22, 2014; Brown, Heather. EC/R, Incorporated. [Memorandum to Bruce Moore, U.S. EPA]. "Composition of natural gas for use in the oil and natural gas sector rulemaking." June 29, 2011.

26 Myhre, Gunnar et al. "Anthropogenic and Natural Radiative Forcing." In Stocker, T. F. et al. (2013). *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge and New York: Cambridge University Press at 714.

27 Stocker, T. F. et al. "Technical Summary." In Stocker, T. F. et al. (2013). *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge and New York: Cambridge University Press at 53.

28 U.S. EPA. Office of Research and Development (ORD). "Study of the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources: Progress Report." EPA 601/R-12/011. December 2012 at 18 to 19 and 43.

29 Adgate, John L. et al. "Potential public health hazards, exposures and health effects from unconventional natural gas development." *Environmental Science & Technology*. Vol. 48, Iss. 15. August 5, 2014 at 8310; U.S. EPA. Office of Air and Radiation (OAR). "Regulatory Impact Analysis: Final New Source Performance Standards and Amendments to the National Emissions Standards for Hazardous Air Pollutants for the Oil and Natural Gas Industry." April 2012 at 4–24.

30 Adgate et al. 2014 at 8310; Vengosh, Avner et al. "A critical review of the risks to water resources from unconventional shale gas development and hydraulic fracturing in the United States." *Environmental Science & Technology*. Vol. 48, Iss. 15. August 5, 2014 at 8338 and 8340.

31 U.S. GAO. "Information on the Quantity, Quality, and Management of Water Produced During Oil and Gas Production." January 9, 2012 at 12.

32 *Ibid*.

33 *Ibid*.; Vengosh et al. 2014 at 8341 to 8342; International Atomic Energy Agency (IAEA). "Radiation Protection and the Management of Radioactive Waste in the Oil and Gas Industry." Safety Reports Series, No. 34. November 2003 at 53 to 54.

34 Goldstein, Bernard D. et al. "The role of toxicological science in meeting the challenges and opportunities of hydraulic fracturing." *Toxicological Sciences*. Vol. 139, Iss. 2 June 2014 at 280; Shonkoff, Seth B. C. et al. "Environmental public health dimensions of shale and tight gas development." *Environmental Health Perspectives*. Vol. 122, Iss. 8. August 2014 at 788.

35 Konschnik, Katherine E. et al. Harvard Law School. Environmental Law Program. "Legal fractures in chemical disclosure laws: Why the voluntary chemical disclosure registry FracFocus fails as a regulatory compliance tool." April 23, 2013 at 1; Brown, David et al. "Understanding exposure from natural gas drilling puts current air standards to the test." *Reviews on Environmental Health*. Preprint, published online March 2014 at 4; U.S. House of Representatives. Committee on Energy and Commerce. [Minority Staff report]. "Chemicals Used in Hydraulic Fracturing." April 2011 at 2.

36 U.S. House Committee on Energy and Commerce. 2011 at 1 and 8; Adgate et al. 2014 at 8308.

37 Reddall (2013); Allen (2014); API. 2014 at 1.

38 DiGiulio, Dominic C. et al. U.S. EPA. [Draft]. "Investigation of *Ground Water* Contamination Near Pavillion, Wyoming." December 2011 at xi.

39 *Ibid*. at xiii.

40 *Ibid*. at 27.

41 Lustgarten, Abrahm. "EPA's abandoned Wyoming fracking study one retreat of many." *ProPublica*. July 3, 2013.

42 *Ibid*.

43 U.S. EPA. [Press release]. "Wyoming to lead further investigation of water quality concerns outside of Pavillion with support of EPA." June 20, 2013.

44 Lustgarten (July 3, 2013).

45 *Ibid*.

46 Pennsylvania Department of Environmental Protection. "Consent Order and Settlement Agreement Between the Commonwealth of Pennsylvania, Department of Environmental Protection and Cabot Oil & Gas Corporation." December 15, 2010 at 2.

47 U.S. EPA. [Press release]. "EPA completes drinking water sampling in Dimock, Pa." July 25, 2012.

48 Lustgarten (July 3, 2013).

49 *Ibid*.

50 U.S. EPA OIG. December 2013 at 16.

51 S. J. Res. 54. 91st Cong. (1969).

52 Amann, Rachel et al. Interstate Oil and Gas Compact Commission. Prepared for U.S. Department of Energy (DOE), National Energy Technology Laboratory (NETL). "New Energy Technologies: Regulating Change." March 17, 2010 at 36.

53 Vengosh et al. 2014 at 8334.

54 Field et al. 2014 at 6, 13, 14 and 31.

55 Rotty, R. M. and G. Marland. Institute for Energy Analysis. Oak Ridge Associated Universities. Prepared for U.S. DOE. "Production of CO2 from Fossil Fuel Burning by Fuel Type: 1860-1982." September 1984 at 12 to 14; Stocker, T. F. et al. 2013 at 50 and 52.

56 Linn, Anne. [Rapporteur]. (2014). "Development of Unconventional Hydrocarbon Resources in the Appalachian Basin: Workshop Summary." Washington, DC: National Academy of Sciences at 5; Hansen, Evan et al. Downstream Strategies and San Jose State University. Prepared for Earthworks Oil & Gas Accountability Project. "Water Resource Reporting and Water Footprint from Marcellus Shale Development in West Virginia and Pennsylvania." October 30, 2013 at 10.

57 Nicot, Jean-Philippe et al. University of Texas at Austin. Jackson School of Geosciences. Prepared for Texas Water Development Board. "Current and Projected Water Use in the Texas Mining and Oil and Gas Industry." June 2011 at 54 and 72.

58 Linn. 2014 at 16; Hansen, Evan et al. 2013 at 31; King, G. "Hydraulic Fracturing 101: What every representative, environmentalist, regulator, reporter, investor, university researcher, neighbor and engineer should know about estimating frac risk and improving frac performance in unconventional gas and oil wells." SPE 152596. Society for Petroleum Engineers Conference at The Woodlands, Texas, February 6–8, 2012 at 10.

59 Linn. 2014 at 16; Hansen, Evan et al. 2013 at 31.

60 U.S. EPA. "Summary of the Technical Workshop on Water Acquisition Modeling: Assessing Impacts Through Modeling and Other Means, June 4, 2013." September 2013 at A–16.

61 *Ibid*. at A–17.

62 *Ibid*.

63 Freyman, Monika and Ryan Salmon. Ceres. "Hydraulic Fracturing & Water Stress: Growing Competitive Pressures for Water." May 2013 at 6.

64 *Ibid*. at 15.

65 *Ibid*. at 7.

66 Nicot, Jean-Philippe, et al. "Source and fate of hydraulic fracturing water in the Barnett shale: A historical perspective." *Environmental Science & Technology*. Vol. 48, Iss. 4. February 18, 2014 at 2467.

67 *Ibid*.

68 Finley, Bruce. "Colorado farms planning for dry spell losing auction bids for water to fracking projects." *Denver Post*. April 1, 2012; Whaley, Monte. "98 percent of Colorado in a drought, say CSU climatologists." April 3, 2012.

69 Ponce, Zack. "Hurt by drought, NM farmers are selling off water intended for irrigation to oil & gas companies for fracking" *Current-Argus News* (NM). January 29, 2014.

70 Linn. 2014 at 5.

71 U.S. EPA. September 2013 at A–16; Souther, Sara et al. "Biotic impacts of energy development from shale: Research priorities and knowledge gaps." *Frontiers in Ecology and the Environment*. Vol. 12, Iss. 6. August 2014 at 334.

72 Winter, Thomas C. et al. U.S. Geological Survey (USGS). "*Ground Water* and Surface Water: A Single Resource." USGS Circular 1139. 1998 at 2 to 5.

73 Souther et al. 2014 at 334.

74 Sloneker, E. T. et al. USGS. "Landscape consequences of natural gas extraction in Bradford and Washington Counties, Pennsylvania, 2004-2010." Open-File Report 2012-1154. 2012 at 5; Entrekin, Sally et al. "Rapid expansion of natural gas development poses a threat to surface waters." *Frontiers in Ecology and the Environment*. Vol. 9, Iss. 9. October 2011 at 508.

75 Musselman, Robert C. and John L. Korfmacher. "Ozone in remote areas of the southern Rocky Mountains." *Atmospheric Environment*. Vol. 82. January 2014 at 383, 384 and 388.

76 Vengosh et al. 2014 at 8339 to 8344; Souther et al. 2014 at 330.

77 Kassotis, Christopher D. et al. "Estrogen and androgen receptor activities of hydraulic fracturing chemicals and surface and ground water in a drilling-dense region." *Endocrinology*. Vol. 155, Iss. 3. March 2014 at 897.

78 Lustgarten, Abrahm. "The trillion-gallon loophole: Lax rules for drillers that inject pollutants into the earth." *ProPublica*. September 20, 2012.

79 Mall and Donnelly. 2010 at 41; Warner, Barbara and Jennifer Shapiro. "Fractured, fragmented federalism: A study in fracking regulatory policy." *Publius: The Journal of Federalism*. Vol. 43, Iss. 3. Summer 2013 at 478.

80 Lustgarten, Abrahm. "Buried secrets: Is natural gas drilling endangering U.S. water supplies?" *ProPublica*. November 13, 2008.

81 Finley, Bruce. "Oil and gas spills surge, two a day, residents often not notified." *Denver Post*. July 29, 2014.

82 Kusnetz, Nicholas. "North Dakota's oil boom brings damage along with prosperity." *ProPublica*. June 7, 2012.

83 Soraghan, Mike. "U.S. well sites in 2012 discharged more than Valdez." *E&E EnergyWire*. July 8, 2013; Soraghan, Mike. "Many mishaps among drillers, but few fines." *E&E EnergyWire*. July 15, 2013.

84 Soraghan, Mike. "Spills up 18 percent in U.S. in 2013." *E&E EnergyWire*. May 12, 2014.

85 Legere, Laura. "DEP: Oil and gas operations damaged water supplies 209 times since end of '07." *Pittsburgh Post-Gazette*. July 22, 2014.

86 Wang, Wei. Louisiana State University. Department of Petroleum Engineering. [PhD dissertation]. "Emergence of Delamination Fractures Around Casing and Its Stability." May 2014 at 2.

87 Hansen, Evan et al. 2013 at 33 and 36; Nicot et al. 2014 at 2465.

88 Hansen, Evan et al. 2013 at 33 and 36; Nicot et al. 2014 at 2465.

89 Hansen, Evan et al. 2013 at 33 and 36; Nicot et al. 2014 at 2465.

90 Lustgarten, Abrahm. "California halts injection of fracking waste, warning it may be contaminating aquifers." *ProPublica*. July 18, 2014.

91 Warner, Nathaniel R. et al. "Impacts of shale gas wastewater disposal on water quality in western Pennsylvania." *Environmental Science & Technology*. Vol. 47, Iss. 20. October 15, 2013 at 11849 to 11852.

92 *Ibid*. at 11850 and 11855.

93 IAEA. 2003 at 50 to 55 and 69; Vengosh et al. 2014 at 8341 and 8342; Kappel, William M. et al. USGS. "Water resources and shale gas/oil production in the Appalachian Basin—Critical issues and evolving developments." Open-File Report 2013–1137. August 15, 2013 at 5 to 6.

94 Banerjee, Neela. "Oil drilling in North Dakota raises concerns about radioactive waste." *Los Angeles Times*. July 26, 2014; McMahon, Jeff. "Fracking truck sets off radiation alarm at landfill." *Forbes*. April 24, 2013.

95 Heyman, Dan. "Concerns over radioactive waste going into WV landfills." *Public News Service*. August 4, 2014.

96 Ek, Derrick. "Truck carrying well drill cuttings overturns near landfill." *The Leader* (Corning, NY). August 31, 2010.

97 Banerjee (July 26, 2014).

98 Kappel et al. 2013 at 5 and 7; North Carolina Departments of Environment and Natural Resources, Commerce, and Justice and RAFI-USA. "North Carolina Oil and Gas Study under Session Law 2011-276." April 2012 at 208.

99 IAEA. 2003 at 52.

100 Vengosh et al. 2014 at 8341; 76 U.S. Fed. Reg. 66286, 66296. October 26, 2011.

101 Wilson, Jessica M. and Jeanne M. Van Briesen. "Source water changes and energy extraction activities in the Monongahela River, 2009–2012." *Environmental Science & Technology*. Vol. 47, Iss. 21. November 5, 2013 at 12575.

102 Vengosh et al. 2014 at 8341; 76 U.S. Fed. Reg. 66297. October 26, 2011; U.S. EPA ORD. December 2012 at 107 to 109.

103 76 U.S. Fed. Reg. 66286. October 26, 2011; U.S. EPA ORD. December 2012 at 102 and 104.

104 Magill, Bobby. "Malfunction sends crude oil spraying 850 feet from well near Severance." *Coloradan*. July 22, 2013; Detrow, Scott. "4,700 gallons of acid spill at Bradford County drilling site." *StateImpact Pennsylvania*. July 5, 2012; Passoth, Kim. "Major oil field spill in Kingfisher County: Concern acidic runoff could reach nearby creek, town water system." KOCO (OK). July 30, 2014.

105 Finley (July 29, 2014); Finley, Bruce. "Drilling spills reaching Colorado groundwater; state mulls test results." *Denver Post*. December 9, 2012.

106 Fontenot, Brian E. et al. "An evaluation of water quality in private drinking water wells near natural gas extraction sites in the Barnett Shale formation." *Environmental Science & Technology*. Vol. 47, Iss. 17. July 15, 2013 at 10037.

107 *Ibid*. at 10032 to 10037.

108 Urbina, Ian. "A tainted water well, and concern there may be more." *New York Times*. August 3, 2011; Energy Resources Conservation Board. "Caltex Energy Inc. hydraulic fracturing incident 16-27-068-10W6M September 22, 2011: ERCB investigation report." December 20, 2012 at 1; Banerjee, Neela. "Oil companies fracking into drinking water sources, new research shows." *Los Angeles Times*. August 12, 2014; Lustgarten (July 18, 2014).

109 Davies et al. 2014 at 239 to 241, 245 and 251.

110 Vengosh et al. 2014 at 8339; Davies et al. 2014 at 239 to 241, 245 and 251; U.S. EPA, Underground Injection Control (UIC) Program. "Permitting Guidance for Oil and Gas Hydraulic Fracturing Activities Using Diesel Fuels: Underground Injection Control Program Guidance #84." February 2014 at A–1 to A–4.

111 Dusseault, M. B. et al. "Why Oilwells Leak: Cement Behavior and Long-Term Consequences." Prepared for presentation at the Society of Petroleum Engineers' International Oil and Gas Conference and Exhibition in Beijing, China. SPE 64733. November 2000 at 1.

112 Osborn, Stephen G. et al. "Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing." *Proceedings of the National Academy of Sciences*. Vol. 8, Iss. 20. April 14, 2011 at 8173.

113 *Ibid*. at 8175.

114 Jackson, Robert B. et al. "Increased stray gas abundance in a subset of drinking water wells near Marcellus shale gas extraction." *Proceedings of the National Academy of Sciences*. Vol. 110, Iss. 28. July 9, 2013 at 11250 and 11251.

115 Vengosh et al. 2014 at 8335; Ohio Department of Natural Resources. "Report on the Investigation of the Natural Gas Invasion of Aquifers in Bainbridge Township of Geauga County, Ohio." September 1, 2008 at 46 to 47.

116 Vengosh et al. 2014 at 8338.

117 Davies et al. 2014 at 241.

118 Kelso, Matt. FracTracker. "Over 1.1 million active oil and gas wells in the US." March 4, 2014.

119 Suro, Robert. "Abandoned oil and gas wells become pollution portals." *New York Times*. May 3, 1992; Davies et al. 2014 at 240, 245, 246 and 247; Kang, Mary. Princeton University. Department of Civil and Environmental Engineering. [PhD dissertation]. "CO2, Methane, and Brine Leakage Though Subsurface Pathways: Exploring Modeling, Measurement, and Policy Options." June 2014 at 1; Ingraffea et al. 2014 at 1.

120 Ellsworth, William L. "Injection-induced earthquakes." *Science*. Vol. 341, No. 6142. July 12, 2013 at 2.

121 *Ibid*. at 2.

122 Ingraffea et al. 2014 at 1.

123 *Ibid*. at 2; Davies et al. 2014 at 243; U.S. EPA UIC. February 2014 at A–1 to A–4.

124 Suro (1992); Davies et al. 2014 at 240, 245, 246 and 247; Kang. 2014 at 1; Ingraffea et al. 2014 at 1.

125 Wang. 2014 at 241.

126 *Ibid*. at 1 and 82.

127 *Ibid*. at 2.

128 *Ibid*. at 82; Vengosh et al. 2014 at 8337; Davies et al. 2014 at 241.
129 Wang. 2014 at 112 to 113.
130 Davies et al. 2014 at 241 and 242.
131 Vengosh et al. 2014 at 8337; Bruffato, Claudio et al. "From mud to cement – building gas wells." *Oilfield Review*. Autumn 2003 at 63; Ingraffea et al. 2014 at 1.
132 Vengosh et al. 2014 at 8337; Bruffato et al. 2003 at 63.
133 Ingraffea et al. 2014 at 1.
134 *Ibid*. at 2.
135 Vengosh et al. 2014 at 8344.
136 *Ibid*.
137 Vaidyanathan, Gayathri. "When 2 wells meet, spills can often follow." *E&E EnergyWire*. August 5, 2013; Vaidyanathan, Gayathri. "Small fortune is lost when oil giant's well collides with family business." *E&E EnergyWire*. October 24, 2013; Vaidyanathan, Gayathri. "As 'frack hits' grew in Alberta, regulators stepped in." *E&E EnergyWire*. January 7, 2014.
138 Vaidyanathan (August 5, 2013).
139 Davies, Richard J. et al. "Hydraulic fractures: How far can they go?" *Marine and Petroleum Geology*. Vol. 37, Iss. 1. November 2012 at 1; Kim, Jihoon and George J. Moridis. "Development of the T+M coupled flow-geomechanical simulator to describe fracture propagation and coupled flow-thermal-geomechanical processes in tight/shale gas systems." *Computers & Geosciences*. Vol. 60. October 2013 at 185.
140 Davies et al. 2014 at 241 and 248; Kappel et al. 2013 at 5.
141 40 CFR §146.1-2; 40 CFR §146.6; U.S. EPA UIC. February 2014 at 1 and 4 to 5.
142 U.S. GAO. "Safeguards Are Not Preventing Contamination From Injected Oil and Gas Wastes." GAO/RCED-89-97. July 1989 at 30 and 31.
143 "The Halliburton Loophole." [Editorial]. *New York Times*. November 2. 2009; Warner and Shapiro. 2013 at 479 to 480; Dannenmaier, Eric. "Executive exclusion and the cloistering of the Cheney Energy Task Force." *New York University Environmental Law Journal*. Vol. 16, Iss. 2. April 2008 at 331.
144 Halliburton. 2013 at 1.
145 U.S. EPA UIC. February 2014 at 9 to 10; 40 CFR §146.6.
146 U.S. EPA UIC. February 2014 at 9 to 10; 40 CFR §146.6.
147 40 CFR §146.6.
148 *Ibid*.
149 *Ibid*.
150 Cutler, Thor and Kurt Hildebrandt. U.S. EPA. Region 10. [Memorandum, Final Work Product from the National UIC Technical Workgroup]. "Does a fixed radius area of review meet the statutory mandate and regulatory requirements of being protective of USDWs under 40 CFR §144.13?" November 5, 2004 at Attachment at 1.
151 *Ibid*. at Attachment at 3.
152 *Ibid*. at Attachment at 4.
153 Codrington, Ann. U.S. EPA. Office of Water. [Memorandum]. "National Technical Workgroup Products 'Annular injection of drilling wastes into production wells' and 'Does a fixed radius area of review meet the statutory mandate and regulatory requirements of being protective of USDWs under 144.12?'" July 2006 at 2.
154 Amann et al. 2010 at 36.
155 S. J. Res. 54. 91st Cong. Article III (1969); Ground Water Protection Council. "Member States: State Agency List." Available at www.gwpc.org/state-agencies. Accessed August 23, 2014.
156 Polson, Jim. "FracFocus fails as fracking disclosure tool, study finds." *Bloomberg*. April 23, 2013; Konschnik et al. 2013 at 1.
157 Greene, Mary. Environmental Integrity Project. "Fracking Beyond the Law: Despite Industry Denials, Investigation Reveals Continued Use of Diesel Fuels in Hydraulic Fracturing." August 13, 2014 at 8.
158 U.S. EPA UIC. February 2014 at 1.
159 *Ibid*. at B–1 to B–7.
160 *Ibid*. at B–2.
161 U.S. GAO. "EPA Program to Protect Underground Sources From Injection of Fluids Associated With Oil and Gas Production Needs Improvement." GAO-14-555. June 2014 at 51 to 53.
162 *Ibid*. at 36 and 37.
163 Myers, Tom. "Potential contaminant pathways from hydraulically fractured shale to aquifers." *Ground Water*. April 17, 2012 at 872.
164 *Ibid*. at 872.
165 Warner, Nathaniel R. et al. "Geochemical evidence for possible natural migration of Marcellus Formation brine to shallow aquifers in Pennsylvania." *Proceedings of the National Academy of Sciences*. Vol. 109, Iss. 30. July 9, 2012 at 11965.
166 Kang, Mary et al. "Analytical solutions for two-phase subsurface flow to a leaky fault considering vertical flow effects and fault properties." *Water Resources Research*. Vol. 50, Iss. 4. April 2014 at 3536.
167 Kang. 2014 at 40 to 41.
168 *Ibid*. at 40 to 43, 46, 52 and 54,
169 U.S. EPA ORD. December 2012 at 62 to 70.
170 *Ibid*. at 70.
171 Moridis, George and Craig M. Freeman. "The RealGas and RealGasH2O options of the TOUGH+ code for the simulation of coupled fluid and heat flow in tight/shale gas systems." *Computers & Geosciences*. Vol. 65. April 2014 at 70.
172 U.S. EPA UIC. February 2014 at B–2.
173 Lustgarten, Abrahm. "Injection wells: the poison beneath us." *ProPublica*. June 21, 2012.
174 Ellsworth. 2013 at 2 and 4; Keranen, K. M. et al. "Sharp increase in central Oklahoma seismicity since 2008 induced by massive wastewater injection." *Science*. Vol. 345, No. 6195. July 25, 2014 at 451.
175 Ellsworth. 2013 at 1.
176 *Ibid*. at 1; U.S. EIA AEO. 2012 at 93.
177 Ellsworth. 2013 at 1.
178 Baldacci, Marlena and Mariano Castillo. "Oklahoma quakes this year top tremos in California." *CNN*. June 20, 2014.
179 Ohio Department of Natural Resources. [Press release]. "Ohio announces tougher permit conditions for drilling activities near faults and areas of seismic activity." April 11, 2014; British Columbia Oil and Gas Commission. "Investigation of Observed Seismicity in the Horn River Basin." August 2012 at 3; Ellsworth. 2013 at 3.
180 Kappel et al. 2013 at 7; Ellsworth. 2013 at 4; Keranen et al. 2014 at 451.
181 Keranen et al. 2014 at 451.
182 Rosenberg, Mica. "Arkansas lawsuits test fracking wastewater link to quakes." *Reuters*. August 27, 2013.
183 Keranen, Katie M. et al. "Potentially induced earthquakes in Oklahoma, USA: Links between wastewater injection and the 2011 Mw 5.7 earthquake sequence." *Geology*. Vol. 41, Iss. 6. June 2013 at 699 to 702.
184 van der Elst, Nicholas J. et al. "Enhanced remote earthquake triggering at fluid-injection sites in the Midwestern United States." *Science*. Vol. 341, Iss. 164. July 12, 2013 at 165.
185 *Ibid*.
186 Ohio Department of Natural Resources. [Press release]. "Ohio announces tougher permit conditions for drilling activities near faults and areas of seismic activity." April 11, 2014; Ellsworth. 2013 at 3.
187 Ellsworth. 2013 at 3 and 4.
188 Wood, Josh. "Lightning a threat to ND saltwater disposal sites." *Associated Press*. July 19, 2014.
189 *Ibid*.
190 U.S. Department of Transportation (DOT). Pipeline and Hazardous Materials Safety Administration (PHMSA). "Operation Safe Delivery Update." July 23, 2014 at 2 and 16.
191 Krauss, Clifford and Jad Mouawad. "Accidents surge as oil Industry takes the train." *New York Times*. January 25, 2014.
192 Moniz, Ernest. Secretary. U.S. DOE. "Secretary Moniz's keynote at the Sam Nunn Policy Forum in Atlanta, GA – as delivered." April 16, 2014.

193 Krauss and Mouawad (2014); Horn, Steve. “Exclusive: Permit shows Bakken Shale oil in Casselton train explosion contained high levels of volatile chemicals.” *DeSmogBlog*. January 5, 2014.

194 U.S. DOT PHMSA. 2014 at 2 and 16.

195 *Ibid*.

196 Yuen, Laura. “Oil train traffic source of worry in Twin Cities.” *Minnesota Public Radio News*. August 11, 2014; de Place, Eric. Sightline Institute. “The Northwest’s Pipeline on Rails: Crude Oil Shipments Planned for Puget Sound, Grays Harbor, and the Columbia River.” May 2014 at 1; Oil Change International. “Runaway Train: The Reckless Expansion of Crude-by-Rail in North America.” May 2014 at 6 and 23.

197 Mapes, Lynda. “Oil train derails in Interbay in Seattle, no spills.” *Seattle Times*. July 24, 2014.

198 de Place. 2014 at 3.

199 National Institute for Occupational Safety and Health. “Hazard Alert: Worker Exposure to Silica during Hydraulic Fracturing.” June 2012; Esswein, Eric J. et al. “Occupational Exposures to Respirable Crystalline Silica During Hydraulic Fracturing.” *Journal of Occupational and Environmental Hygiene Times*. July 2013 at 347.

200 Mertens, Richard. “Next fracking controversy: In the Midwest, a storm brews over ‘frac sand’.” *Christian Science Monitor*. March 9, 2014; Auch, Ted. FracTracker. “Frac sands mines and related facilities.” December 2, 2013.

201 Adgate et al. 2014 at 8310.

202 Esswein et al. 2013 at 347.

203 Smathers, Jason. “Sand mining surges in Wisconsin.” *Wisconsin Watch*. July 31, 2011.

204 Moore, Christopher W. et al. “Air impacts of increased natural gas acquisition, processing, and use: A critical review.” *Environmental Science & Technology*. Vol. 48, Iss. 15. August 5, 2014 at 8353.

205 “Wisconsin school district boosts frac sand air filters.” *Minnesota Public Radio News*. November 3, 2013

206 Adgate et al. 2014 at 8308; U.S. EPA OAR. April 2012 at 4–4; U.S. EPA OIG. “EPA Needs to Improve Air Emissions Data for the Oil and Natural Gas Production Sector.” Report No. 13-P-0161. February 20, 2013 at 2.

207 Litovitz, Aviva et al. “Supplemental data for ‘Estimation of regional air-quality damages from Marcellus Shale natural gas extraction in Pennsylvania.’” *Environmental Research Letters*. Vol. 8, Iss. 1. January-March 2013 at 2.

208 Adgate et al. 2014 at 8310.

209 Wood, Josh. “Lightning a threat to ND saltwater disposal sites.” *Associated Press*. July 19, 2014; Gunderson, Dan and Elizabeth Dunbar. “Huge N.D. oil spill burns into second day; weather shift threatens Casselton.” *Associated Press*. December 31, 2013; Hardaway, Ashlie and Matt Belanger. “One fire out, second still burning at Chevron natural gas well blast in Greene County.” *WTAE.com* (Pittsburgh). February 13, 2014.

210 U.S. EPA OIG. February 2013 at 2 and 3; Adgate et al. 2014 at 8308.

211 Brown et al. 2014 at 3; U.S. EPA OAR. April 2012 at 2; Alvarez, Ramon A. et al. “Greater focus needed on methane leakage from natural gas infrastructure.” *Proceedings of the National Academy of Sciences*. Vol. 109, Iss. 17. April 9, 2012 at 6437.

212 Stocker, T. F. et al. 2013 at 53; Myhre et al. 2013 at 714.

213 Adgate et al. 2014 at 8308; U.S. House Committee on Energy and Commerce. 2011 at 10; U.S. EPA OAR. April 2012 at 4–15 to 4–18.

214 U.S. EPA OAR. April 2012 at 4–4, 4–25 and 4–26.

215 *Ibid*. at 4–24.

216 Adgate et al. 2014 at 8310.

217 Goldstein et al. 2014 at 279 to 280; Shonkoff et al. 2014 at 788; Brown et al. 2014 at 4.

218 McIntire, Mike. “Conservative nonprofit acts as a stealth business lobbyist.” *New York Times*. April 21, 2012; Currier, Cora. “ALEC and ExxonMobil push loopholes in fracking chemical disclosure rules.” *ProPublica*, April 24, 2012.

219 Arenschield, Laura. “Halliburton delayed releasing details on fracking chemicals after Monroe County spill.” *Columbus Dispatch*. July 22, 2014.

220 Souther et al. 2014 at 333; Konschnik et al. 2013 at 1; Brown et al. 2014 at 4.

221 U.S. House Committee on Energy and Commerce. 2011 at 2.

222 Shonkoff et al. 2014 at 789; Kassotis et al. 2014 at 897.

223 Kassotis et al. 2014 at 900.

224 U.S. House Committee on Energy and Commerce. 2011 at 1 and 8.

225 Adgate et al. 2014 at 8308.

226 Goldstein et al. 2014 at 279 to 280; Shonkoff et al. 2014 at 788.

227 Moore et al. 2014 at 8354; U.S. EPA OIG. February 2013 at 6.

228 Moore et al. 2014 at 8354; Brandt, A. R. et al. “Supplementary materials for ‘Methane leaks from North American natural gas systems’.” 2014 at 36; U.S. EPA OIG. February 2013 at 6.

229 Moore et al. 2014 at 8354; U.S. EPA OIG. February 2013 at 6.

230 Kang. 2014 at 56, 58, 76 and 77.

231 U.S. EPA OIG. February 2013 at 3 to 5; U.S. EPA. “Inventory of U.S. Greenhouse Gas Emissions and Sinks (GHGI): 1990-2012.” EPA 430-R-14-003. April 15, 2014 at 3–65.

232 U.S. EPA OIG. February 2013 at 3 to 5; U.S. EPA GHGI. April 2014 at 3–65.

233 U.S. EPA OIG. February 2013 at 3 to 5; U.S. EPA GHGI. April 2014 at 3–65 to 3–67.

234 U.S. EPA OIG. February 2013 at 15 and 17.

235 *Ibid*. at 14.

236 Pétron, Gabrielle et al. “A new look at methane and non-methane hydrocarbon emissions from oil and natural gas operations in the Colorado Denver-Julesburg Basin.” *Journal of Geophysical Research: Atmospheres*. Vol. 119, Iss. 11. June 16, 2014 at 6840.

237 *Ibid*.; Caulton, Dana R. et al. “Toward a better understanding and quantification of methane emissions from shale gas development.” *Proceedings of the National Academy of Sciences*. Vol. 111, Iss. 17. April 29, 2014 at 6238; Pétron, Gabrielle et al. “Hydrocarbon emissions characterization in the Colorado Front Range: A pilot study.” *Journal of Geophysical Research: Atmospheres*. Vol. 117, Iss. D4. February 21, 2012; Karion, Anna et al. “Methane emissions estimate from airborne measurements over a western United States natural gas field.” *Geophysical Research Letters*. Vol. 40. August 27, 2013 at 4393; Brandt, A. R. et al. “Supplementary materials for ‘Methane leaks from North American natural gas systems’.” 2014 at 29.

238 Karion et al. 2013 at 4393.

239 Caulton et al. 2014 at 6239 and 6241.

240 Pétron et al. 2014 at 6836.

241 *Ibid*.

242 Bamberger, M. and R. E. Oswald. “Impacts of gas drilling on human on animal health.” *New Solutions*. Vol. 22, Iss. 1. 2012 at 51.

243 Food & Water Watch calculation based on: Miller, Scot M. et al. “Anthropogenic emissions of methane in the United States.” *Proceedings of the National Academy of Sciences*. Vol. 110, Iss. 50. December 10, 2013 at 5; U.S. EPA. “Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010.” EPA 430-R-12-001. April 15, 2012 at 2–5; and U.S. EIA. “Natural gas consumption by end use.” Available at www.eia.gov/dnav/ng/ng_cons_sum_dcu_nus_a.htm. Accessed August 13, 2014.

244 Brandt, A. R. et al. “Supplementary materials for ‘Methane leaks from North American natural gas systems’.” 2014 at 29.

245 Brandt, A. R. et al. “Methane leaks from North American natural gas systems.” *Science*. Vol. 343, Iss. 733. February 14, 2014 at 733; Howarth, Robert W. “A bridge to nowhere: Methane emissions and the greenhouse gas footprint of natural gas.” *Energy Science & Engineering*. Preprint, published online May 20, 2014 at Abstract.

246 Food & Water Watch calculation based on U.S. EPA GHGI. April 2014 at 3–6 and ES–5 to ES–7.

247 U.S. EPA. “Annexes to the Inventory of U.S. Greenhouse Gas Emissions and Sinks.” April 15, 2014 at A–397 to A–400.

248 *Ibid*.

249 Myhre et al. 2013 at 714; U.S. EPA GHGI. April 2014 at 1–9.

250 Myhre et al. 2013 at 714.

251 U.S. EPA GHGI. April 2014 at 1–9.

252 *Ibid*. at 1–9.

253 Flavin, Christopher and Nicholas Lenssen. *Power Surge: Guide to the Coming Energy Revolution*. W. W. Norton: New York. 1994 at 91 and 92; Energy Modeling Forum. Stanford University. "Natural Gas, Fuel Diversity and North American Energy Markets." Report 20. September 2003 at 1; Podesta, John D. and Timothy E. Wirth. Center for American Progress. "Natural Gas: A Bridge Fuel for the 21st Century." August 10, 2009 at 1; Jaffe, Amy M. "Shale gas will rock the world." *Wall Street Journal*. May 10, 2010.

254 Baker Hughes. "North America Rotary Rig Count." August 8, 2014.

255 Schellnhuber, Hans J. et al. German Advisory Council on Global Change. "World in Transition – A Social Contract for Sustainability." 2011 at 112 to 113; McKibben, Bill. "Global warming's terrifying new math." *Rolling Stone*. July 19, 2012.

256 Afsah, Shakeb and Kendyl Salcito. CO2 Scorecard. "Demand reduction slashes US CO2 emissions in 2012." May 1, 2013; Renewable Energy Policy Network for the 21st Century (REN21). "Renewables 2014: Global Status Report." 2014 at 27 and 69.

257 Afsah, Shakeb and Kendyl Salcito. CO2 Scorecard. "Shale gas: Killing coal without cutting CO2." December 2, 2013.

258 Revkin, Andrew. "U.S. coal exports eroding domestic greenhouse gains." *New York Times*. July 28, 2014.

259 Alvarez et al. 2012 at 6438.

260 Brandt, A. R. et al. "Methane leaks from North American natural gas systems." 2014 at 733; Howarth. 2014 at Abstract.

261 Edwards, Morgan R. and Jessika E. Trancik. "Climate impacts of energy technologies depend on emissions timing." *Nature Climate Change*. Vol. 4, Iss. 5. April 25, 2014 at 347.

262 *Ibid*. at 348.

263 Myhre et al. 2013 at 714.

264 Howarth. 2014 at 7 to 9; Hansen, James et al. 2013 at 13 to 15; Spratt, David. "The real budgetary emergency & the myth of 'burnable carbon'." *Climate Code Red*. May 22, 2014.

265 Hansen, James et al. 2013 at 13 to 15; Spratt (May 22, 2014).

266 Vinas, Maria-Jose. "NSIDC, NASA say Arctic melt season lengthening, ocean rapidly warming." *NASA, Earth Science News*. March 31, 2014.

267 Hansen, James et al. 2013 at 14.

268 Moskvitch, Katia. "Mysterious Siberian crater attributed to methane: Build-up and release of gas from thawing permafrost most probable explanation, says Russian team." *Nature News*. July 31, 2014.

269 Hansen, James et al. 2013 at 4; Anderson, Kevin and Alice Bows. "Beyond 'dangerous' climate change: emission scenarios for a new world." *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*. Vol. 369, Iss. 1934. January 13, 2011 at 20; Roberts, David. "The brutal logic of climate change." *Grist*. December 6, 2011.

270 Hansen, James et al. 2013 at 10 and 20; Spratt (May 22, 2014); Doyle, Alister. "Deep emissions cuts needed by 2050 to limit warming-UN draft." *Reuters*. August 7, 2014.

271 Alvarez et al. 2012 at 6437.

272 Brandt, A. R. et al. "Supplementary materials for 'Methane leaks from North American natural gas systems'." 2014 at 29; Alvarez et al. 2012 at 6437.

273 Hamburg, Steven. Environmental Defense Fund. "Methane: A Key to Dealing With Carbon Pollution?" November 5, 2013.

274 Howarth. 2014 at 10; Hamburg (2013).

275 Hamburg (2013).

276 Food & Water Watch calculation, see endnote 243.

277 Brandt, A. R. et al. "Methane leaks from North American natural gas systems." 2014 at 733; Howarth. 2014 at 5.

278 Newell, Richard G. and Daniel Raimi. "Implications of shale gas development for climate change." *Environmental Science & Technology*. Vol. 48, Iss. 15. August 5, 2014 at 8360; Myhrvold, Nathan and Ken Caldeira. "Greenhouse gases, climate change and the transition from coal to low-carbon electricity." *Environmental Research Letters*. Vol. 7, Iss. 1. February 2012 at 4 to 5; Wigley, Tom M.L. "Coal to gas: The influence of methane leakage." *Climatic Change*. Vol. 108, Iss. 3. August 26, 2011 at 606; IEA. "Golden rules for a golden age of gas." 2012 at 91.

279 IEA. "Golden rules for a golden age of gas." 2012 at 91.

280 Hansen et al. 2013 at 1.

281 Field et al. 2014 at 11 to 20.

282 Roberts (October 27, 2011); Nelder (October 19, 2011).

283 U.S. EPA. "Regulatory Impact Analysis for the Proposed Carbon Pollution Guidelines for Existing Power Plants and Emission Standards for Modified and Reconstructed Power Plants." June 2014 at 3–26 and 3–35.

284 Food & Water Watch. November 2012 at 7 to 12; Stockman. 2013 at 4 and 11; Lux Research. [Press release]. "Shale gas drives $120 billion worth of LNG projects in North America." May 14, 2014.

285 Food & Water Watch calculation based on: U.S. DOE. Office of Fossil Fuels. "Summary of LNG export applications of the lower 48 states." July 31, 2014; and U.S. EIA. "U.S. dry natural gas production." Available at www.eia.gov/dnav/ng/hist/n9070us2a.htm. Accessed August 15, 2014.

286 U.S. EIA. "Annual Energy Outlook 2014 With Projections to 2040." DOE/EIA-0383(2014). April 2014 at MT-23.

287 Lustgarten, Abrahm and Nicholas Kusnetz. "Science lags as health problems emerge near gas fields." *ProPublica*. September 16, 2011; Steinzor, Nadia et al. "Investigating links between shale gas development and health impacts through a community survey project in Pennsylvania." *New Solutions*. Vol. 23, Iss. 1. 2013 at 55 to 83; Steel Valley Printers. "Shalefield Stories; Personal and Collected Testimonies." January 2014; Pennsylvania Alliance for Clean Air and Water. "List of the harmed." June 8, 2014.

288 Brown et al. 2014 at 1.

289 *Ibid*. at 11.

290 *Ibid*. at 2 to 3.

291 Begos, Kevin. "Expert: Pa. didn't address fracturing health impacts." *Associated Press*. July 12, 2014; Colaneri, Katie. "Former state health employees say they were silenced on drilling." *StateImpact Pennsylvania*. June 19, 2014.

292 McKenzie, Lisa M. et al. "Human health risk assessment of air emissions from development of unconventional natural gas resources." *Science of the Total Environment*. Vol. 424. May 1, 2012 at 79.

293 McKenzie, Lisa M. et al. "Birth outcomes and maternal residential proximity to natural gas development in rural Colorado." *Environmental Health Perspectives*. Vol. 122, No. 4. April 2014 at 412.

294 U.S. EPA OIG. February 2013 at 2; Moore et al. 2014 at 8354; Musselman and Korfmacher. 2014 at 383, 384 and 388.

295 Goldstein et al. 2014 at 280; Shonkoff et al. 2014 at 788.

296 Maryland Institute for Applied Environmental Health. School of Public Health. University of Maryland. "Potential Public Health Impacts of Natural Gas Development and Production in the Marcellus Shale in Western Maryland." July 2014 at 16 to 18.

297 Adgate et al. 2014 at 8314 to 8315; Jacquet, Jeffrey B. "Review of risks to communities from shale energy development." *Environmental Science & Technology*. Vol. 48, Iss. 15. August 5, 2014 at 8321; Weber, Bret A. et al. "Rural North Dakota's Oil Boom and Its Impact on Social Services." *Social Work*. Vol. 59, Iss. 1. January 19, 2014 at 62.

298 American Public Health Association (APHA). "The environmental and occupational health impacts of high-volume hydraulic fracturing of unconventional gas reserves." Policy statement 20125. October 30, 2012; APHA. [Press release]. "American Public Health Association adopted 12 new policy statements at 140th Annual Meeting." January 3, 2013.

299 Steinzor et al. 2013 at 55 to 83; Steel Valley Printers (January 2014); Pennsylvania Alliance for Clean Air and Water (June 8, 2014); Jacquet. 2014 at 8321 to 8333; Weber et al. 2014 at 62 to 72.

300 Barth, Janette. "The economic impacts of shale gas development on state and local economies: Benefits, costs, and uncertainties." *New Solutions*. Vol. 23, Iss. 1. 2013 at 86.

301 *Ibid*. at 94 to 95; Gopalakrishnan, Sathya and H. Allen Klaiber. "Is the shale energy boom a bust for nearby residents? Evidence from housing values in Pennsylvania." *American Journal of Agricultural Economics*. Vol. 96, Iss. 1. January 2014 at 43.

302 Food & Water Watch. "The Social Costs of Fracking: A Pennsylvania Case Study." September 2013 at 3 to 4 and 7 to 8; Weber et al. 2014 at 64; Maryland Institute for Applied Environmental Health. July 2014 at xix to xx.

303 Barth. 2013 at 92 to 93; Vaidyanathan, Gayathri. "Dairy farms on the decline across the Marcellus Shale." *E&E EnergyWire*. March 13, 2012.

304 Williamson, Jonathon et al. "Marcellus Natural Gas Development's Effect on Housing in Pennsylvania." Lycoming College, Center for the Study of Community and the Economy. October 31, 2011 at 5 and 17; U.S. Department of Housing and Urban Development. "Tackling the Housing Crisis in Pennsylvania's Boomtowns." April 19, 2012.

305 Jacquet. 2014 at 8322.

306 Weber et al. 2014 at 68.

307 Christopherson, Susan and Ned Rightor. "How shale gas extraction affects drilling localities: Lessons for regional and city policy makers." *International Journal of Town and City Management*. Vol. 2. Iss. 4. March 2012 at 3 to 5; Barth. 2013 at 87 to 89.

308 Jacquet. 2014 at 8322.

309 Christopherson and Rightor. 2012 at 10; Barth. 2013 at 87.

310 Jacquet. 2014 at 8326.

311 Barth. 2013 at 92 to 93; Christopherson and Rightor. 2012 at 2; Vaidyanathan (March 13, 2012); Rumbach, Andrew. Prepared for the Southern Tier Central Regional Planning and Development Board (NY). "Natural Gas Drilling in the Marcellus Shale: Potential Impacts on the Tourism Economy of the Southern Tier." July 2011 at 6, 10 and 19.

312 Jacquet. 2014 at 8322.

313 Warner and Shapiro. 2013 at 474 to 475 and 478 to 480.

314 Rabe. 2014 at 8371 and 8374.

315 Campanale, Mark and Jeremy Leggett. Carbon Tracker Initiative. "Unburnable Carbon: Are the world's financial markets carrying a carbon bubble?" July 2011 at 2 and 6; IEA. "World Energy Outlook 2012." 2012 at 259; Hansen, James et al. 2013 at 3; Field, Christopher et al. "Technical Summary for Policymakers." In Field, Christopher et al. (2014). *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change: Summary for Policymakers*. New York: Cambridge University Press at 14.

316 Afsah and Salcito (May 1, 2013); REN21. 2014 at 27 and 69; Biello, David. "Fracking hammers clean energy research." *Scientific American*. March 20, 2014; Arnsdorf, Isaac. "Fracking sucks money from wind while China eclipses U.S." *Bloomberg News*. May 29, 2014.

317 *See* Food & Water Watch, Fracking Action Center, Local Actions Against Fracking; Heller, Gernot. "German Environment Agency calls for rules preventing fracking." *Reuters*. July 30, 2014; Jolly, David. "France upholds ban on hydraulic fracturing." *New York Times*. October 22, 2013.

318 Hansen et al. 2013 at 18; Steingraber, Sandra. "A new environmentalism for an unfractured future." *EcoWatch*. June 6, 2014; Princen, Thomas. "The Politics of Urgent Transition: Fossil Fuel Exit and the Localization of Attention." In Wolinsky-Nahmias, Yael. (2014). *Changing Climate Politics: U.S. Policies and Civic Society*. Thousand Oaks, California: CQ Press at 225 to 232; "Hermann Scheer (1944-2010): German lawmaker, leading advocate for solar energy and 'hero for the Green Century' in one of his final interviews." Transcript. *Democracy Now!* October 15, 2010.

319 Sierra Club and Oil Change International. 2014 at 2; Nelder, Chris. "Energy policy: Follow the money." *SmartPlanet*. August 8, 2012; Sierra Club. "Clean energy under siege: Following the money trail behind the attack on renewable energy." August 2012 at 1 and 6; Aguilar, John and Megan Quinn. "Colorado Oil and Gas Association gives $600K to fight fracking bans on Front Range ballots." *Daily Camera* (Boulder, CO). October 16, 2013; Energy Tomorrow, American Petroleum Institute. Sample advertisements available at http://energytomorrow.org/digital-resources. Accessed August 23, 2014; America's Natural Gas Alliance. Sample advertisements available at www.anga.us/media-room/advertising. Accessed August 23, 2014; America's Natural Gas Alliance. Sample advertisements available at www.anga.us/why-natural-gas. Accessed August 23, 2014.

320 Lopez, Anthony et al. U.S. DOE NETL. "U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis." NREL/TP-6A20-51946. July 2012 at 20; *See* The Solutions Project. Available at http://thesolutionsproject.org/. Accessed August 23, 2014; *See* PSE Healthy Energy. "Running on Renewables: A review of 80%–100% renewable electricity scenarios." June 2014.

Food & Water Europe

Brussels Office
26, rue d'Edimbourg
1050 Brussels
Belgium
0032 (0)2 893.10.45
foodandwatereurope.org