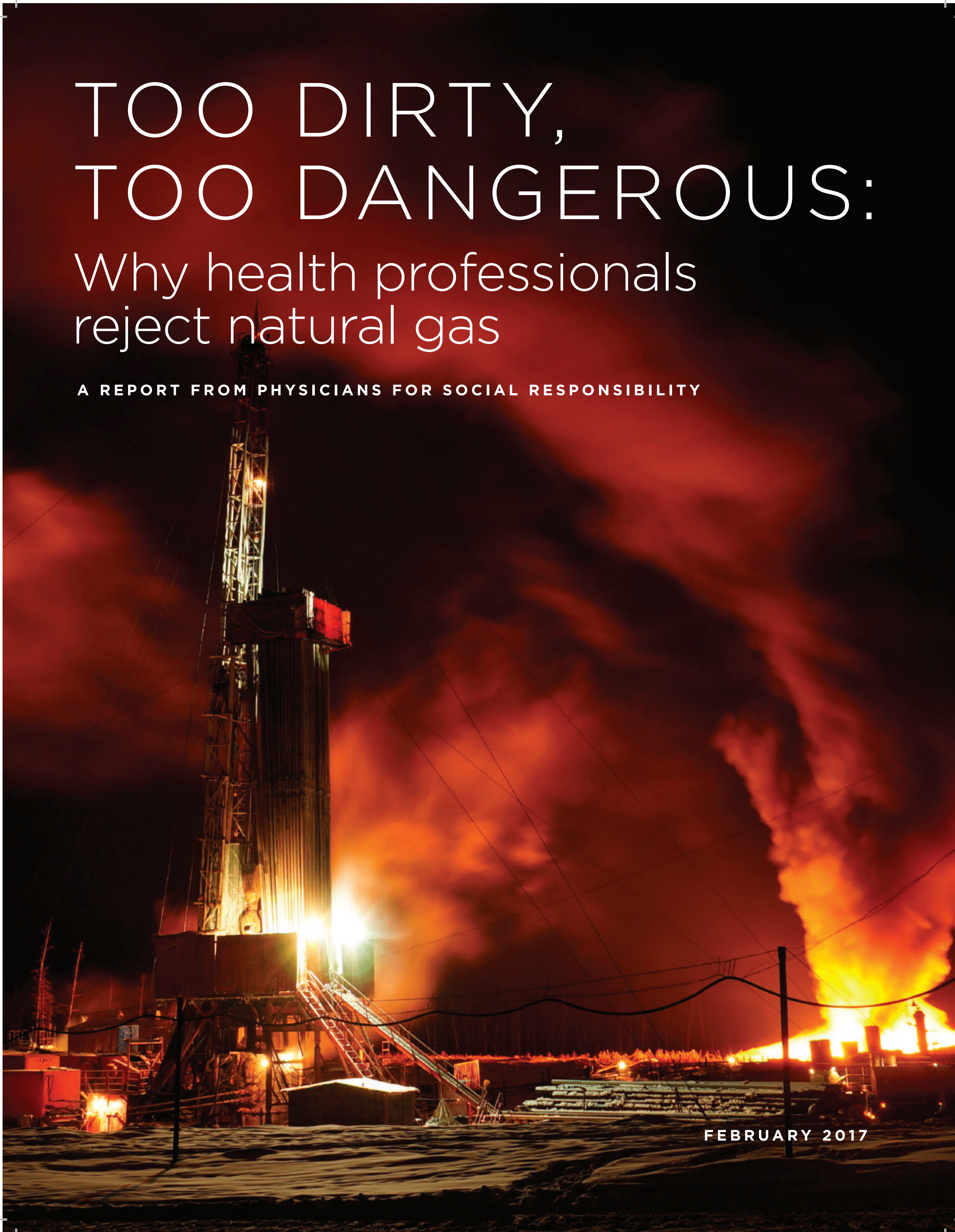
TOO DIRTY, TOO DANGEROUS:

Why health professionals reject natural gas

A REPORT FROM PHYSICIANS FOR SOCIAL RESPONSIBILITY



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Too Dirty, Too Dangerous: Why Health Professionals Reject Natural Gas

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Fracking can cause water and air pollution and extensive leakage of methane into the atmosphere.

PHOTO: David R. Tribble

EXECUTIVE SUMMARY

There are compelling reasons to question the use of natural gas (methane), given the risks it poses to human health. This report summarizes recent scientific findings that document methane's implications for health.

Methane extraction, especially by means of high-volume horizontal hydraulic fracturing (fracking), releases methane and dangerous toxic substances into the water and air. So do the subsequent processing, transport and delivery of methane. We classify the associated health threats into two broad categories: those caused by exposure to toxic substances, and those associated with methane's effects on the climate.

TOXIC EXPOSURES

A. WATER CONTAMINATION

In fracking, a complex mixture of chemicals is combined with millions of gallons of water, then pumped deep underground under high pressure to fracture rock, thus releasing tiny bubbles of gas or oil. The list of chemicals used in fracking fluids is considered proprietary business information and is not always made public. However, some fracking fluids contain benzene (known to cause leukemia and other blood cancers), formaldehyde (a known carcinogen), and petroleum distillate (toxins which would render water undrinkable). Where people are exposed to fracking fluids but disclosure of the chemicals involved is not required, health professionals may have to guess at toxicity, thus complicating or delaying treatment.

Some of the chemical-water fracking mixture routinely remains underground, where it can migrate into underground water supplies; methane and fracking chemicals have been found in drinking-water wells near fracking sites. The fracking wastewater that is removed from the well is generally so severely contaminated that conventional water treatment facilities cannot purify it. Its disposal poses a host of new problems, from ground and water contamination to earthquakes.

B. AIR CONTAMINATION

Fracking releases toxic substances not only into the water but also into the air. One of the most dangerous is particulate matter, which causes or contributes to lung diseases like COPD and lung cancer, heart effects including heart attack and congestive heart failure, and ischemic stroke. Fracking also releases volatile organic compounds (VOC's) such as benzene and formaldehyde, both of which are known carcinogens; toluene, associated with mental disabilities and abnormal growth in children, as well as damage to the kidney, liver, and immune and reproductive systems; and xylene, which can affect the nervous system, kidneys, lungs and heart. VOC's also contribute to ground-level ozone, a pollutant that can reduce lung function and worsen bronchitis, emphysema and asthma. Radioactive substances like radon can accompany methane; radon is a potent cause of lung cancer. The full list of dangerous substances is far longer. Because fracking is conducted in rural, suburban and even urban areas, it exposes over 15 million Americans to the toxic substances used in and around drilling sites.

Some of these health risks are not limited to the fracking site. The pipelines and compressor stations that transport fracked gas hundreds of miles from well sites can leak, exposing distant populations to dangerous substances that travel through the pipelines along with the methane; these include, notably, particulate matter, volatile organic

compounds, and radon and its radioactive decay products. This infrastructure also carries the risk of explosions and intense fires.

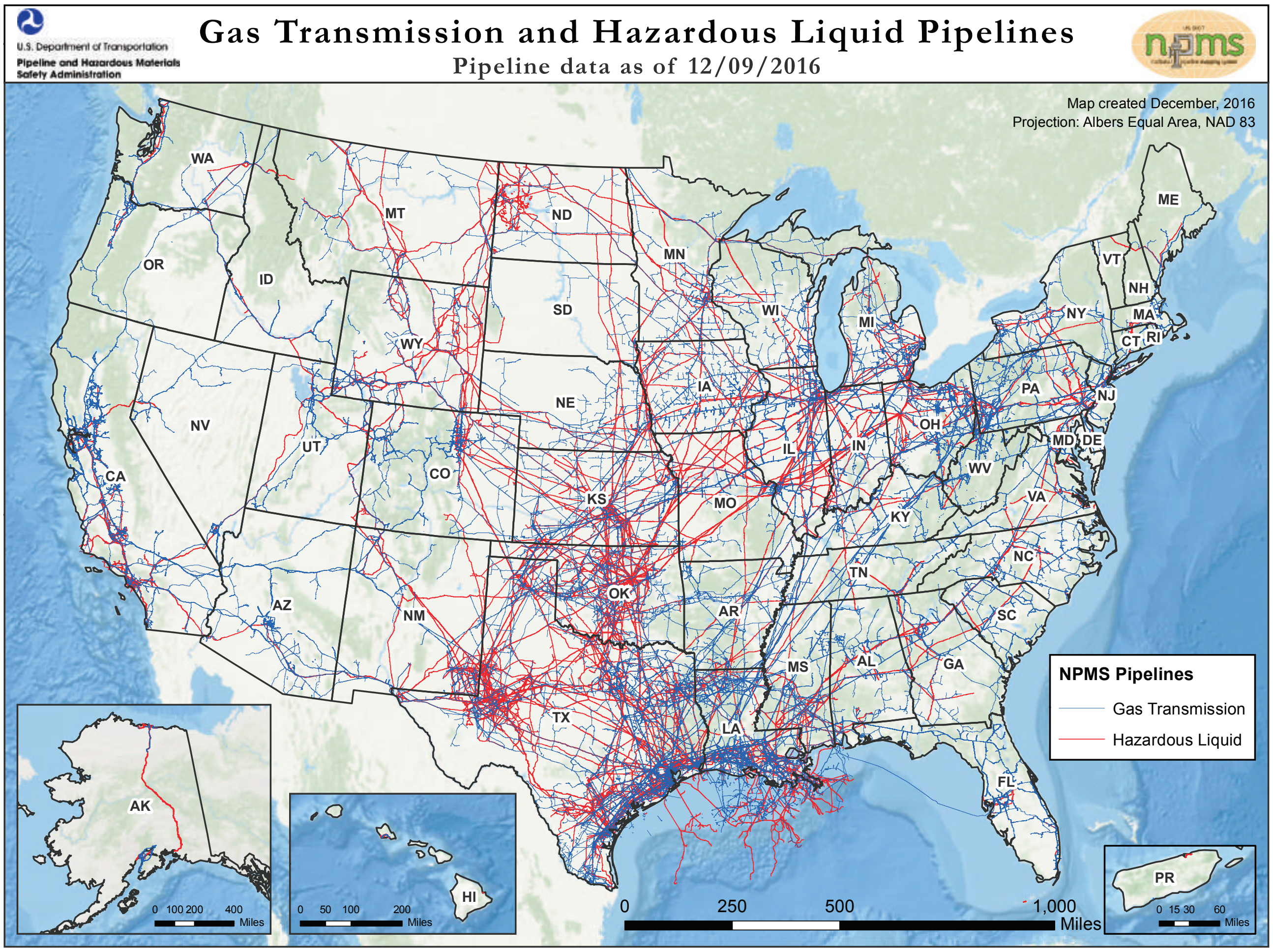
C. HEALTH OUTCOMES

The risks from exposure to fracking-related toxics are not theoretical. Evidence is accumulating that exposure to fracking-related substances has caused serious health effects. Proximity to fracking sites has been shown to be associated with an increase in various health symptoms. Some, such as migraine headaches, severe fatigue and nosebleeds, may indicate underlying health impacts whose causes and implications may not be fully understood. Research indicates certain health outcomes associated with proximity to fracking sites are immediately understood to be serious; these include the increase in high-risk pregnancies, birth defects and premature births. (Premature birth is a leading cause of infant death.) Other health outcomes may not manifest for years, given their long latency periods, but peer-reviewed research shows a clear link between early life exposures to some of the chemicals used in fracking and eventual adverse health effects. Evidence also links fracking to effects on farm animals, including stillbirths and deaths. Fracking's impact on the food supply is not yet known.

FRACKING AND CLIMATE CHANGE

A. CLIMATE IMPACTS ON HEALTH

Methane is an extremely potent climate change gas, 86 times more potent than carbon dioxide over its first 20 years in the atmosphere. As such, it contributes to the host of threats to health known to be associated with climate change here and around the world. These include heat waves, which are the most lethal impact of climate



change in the United States; the spread of diseases carried by insects and other vectors, such as West Nile disease, malaria, and Lyme disease; intense hurricanes, storms, and sea level rise; flooding, which may cause water contamination and destruction of homes and crops; and droughts, wildfires, and decreased crop yields.

B. LEAKAGE AND TIPPING POINTS

Methane leakage into the atmosphere is a problem whose magnitude is now being reassessed: Rates of leakage appear significantly higher than was previously calculated, especially from fracked wells, both active and abandoned; infrastructure including compressor stations; and pipelines, including distribution pipelines for heating and cooking. Large storage facilities, such as Aliso Canyon in California, have emerged as another source of methane leakage. The cumulative impact of this leakage may overwhelm the apparent climate advantage of burning methane gas instead of coal for power generation.

Due to tipping points in the climate system, the next 20-30 years will be decisive in determining the extent of climate change impacts. With air and ocean temperatures rising worldwide, we are in danger of surpassing the critical threshold of a greater than 2° C temperature increase. If that happens, much of the world's permafrost will melt. The result: vast amounts of carbon dioxide and methane will be released, yielding even greater climate change acceleration; more parts of the world would reach unlivable temperatures. The critical need to avoid such a climate crisis requires that we take into account methane's near-term warming impacts and act expeditiously.

CONCLUSIONS

Our nation's policies and practices must recognize and respond to these grave health hazards. Industry and government action to stem methane leaks are welcome steps in the right direction but are inadequate: they reduce but do not resolve methane leakage and toxic threats. Therefore, Physicians for Social Responsibility calls for a full and honest assessment of methane gas's impacts on health, including the following steps to protect human health:

- Calculate methane's climate-forcing potential based on its impact over its first twenty years in the atmosphere;
- Develop a thorough inventory of methane gas leakage across its entire lifecycle; and
- Appraise the toxic risks associated with methane, including at the points of extraction, processing, transport and distribution.
- Ensure that natural gas projects are subject to fundamental health-protective policy, including the Clean Water Act, Clean Air Act, and the Resource Conservation and Recovery Act.
- Require companies conducting hydraulic fracturing to fully and transparently declare the chemicals they use in those processes.
- Require federal, state and local governments to prioritize the protection of human health in their decisions concerning gas-related projects.

These factors should inform public policy and should lead to the phasing-out of methane gas.

Finally, to meet our nation's need for abundant energy, PSR calls for a swift and equitable transition to the production and deployment of energy efficiency and virtually carbon-free renewable energy sources including solar, wind and geothermal power. Our health and that of future generations deserve and depend on a clean energy future.

Fracking can cause water and air pollution and extensive leakage of methane into the atmosphere.

PHOTO: EcoFlight

METHANE GAS ACCELERATES CLIMATE DISASTER

What should be the role of natural gas in our nation's energy mix, given the need to reduce greenhouse gas emissions? How severely does natural gas impact the climate? What are its other effects on human health? These questions are at the heart of an active debate that has grown more urgent as coal-fired power plants are retired. The answers that are emerging indicate that we must reassess the value of natural gas as a fuel—especially as U.S. methane emissions have increased by more than 30 percent over the past decade[1] and methane has overtaken coal as the most-used fuel in electricity production.[2]

METHANE, A MAJOR GREENHOUSE GAS

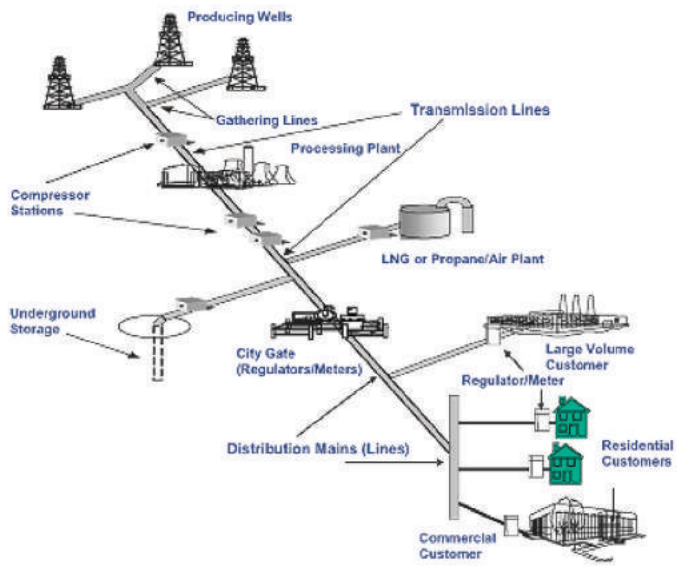
Climate scientists know that the burning of fossil fuels is driving much of the increase in global temperatures over the past 65 years.[3] About a third of the greenhouse gases propelling that increase come from burning coal to produce electricity. Natural gas, whose primary ingredient is methane, is often proposed as an alternative to coal, since when burned it emits only about half as much carbon dioxide.[4] But that comparison holds true only at the point of combustion. Due to leaking methane, which escapes across the natural gas supply chain from the well head to the end user, natural gas's effect on the climate is greater, perhaps much greater. That's because while it is in the atmosphere, methane has a much stronger heat-retaining impact than carbon dioxide. And while a methane molecule lasts only 12.4 years in the atmosphere, it breaks down into carbon dioxide (CO_2) and water vapor, and those greenhouse gases extend methane's impact on the climate for decades. Over a 20-year timeframe, methane is 86 times more potent at trapping heat than CO_2, according to the IPCC.[5]

Those 20 years are an appropriate timeframe to consider, given that it is roughly the window of opportunity that remains for us to slow climate change. If we don't contain greenhouse gas levels in the coming years, we are likely to see world temperatures increase more than 1.5°C to 2°C above preindustrial levels, the limit the U.S. and most of the world's nations agreed to in the 2015 Paris Accords. Increases beyond those levels are likely to melt much of the world's permafrost,[6] releasing such vast quantities of stored methane and carbon dioxide that the world would experience climate change irreversible on a human time scale.[5, 7] The critical need to avoid that tipping point requires that we assess natural gas's powerful impact on our climate, including the impacts of leakage from natural gas facilities, and act appropriately.

METHANE LEAKAGE FROM NATURAL GAS EXTRACTION

A growing body of scientific evidence shows that methane leaks into the atmosphere during every phase of the natural gas supply chain: from drilling sites, processing, transport, storage and final distribution. The rate of that methane leakage is hotly debated. A 2016 study found that researchers' estimates of leaks across the supply chain ranged from 0.2 to 10 percent of produced methane,[8] with the variation due in part to inherent difficulties in measuring leaks.

The most precise measurements are taken when scientists can go directly to the field (well sites, drilling and processing equipment, pipelines or other pieces of infrastructure) and measure the methane leakage, then extrapolate from an average of those measurements. These "bottom-up" studies have high internal validity, that is, the data are generally accurate for the sites where they are taken. However they lack corresponding high external validity, meaning that generalizing those results is not reliable; for example, a relatively small database of samples is likely to under-represent infrequent but high-emission events such as venting and accidental leaks (or by the same token, the infrequent low-emitting, ideally managed



Natural gas industry, from production through distribution.
SOURCE: EPA

well site). However, developing a large and statistically random database is difficult: site-by-site data collection is labor-intensive and time-consuming; access to fracking sites is often restricted, whether by the drilling company or the land owner; and databases are likely to miss the numerous small leaks that have been found to occur in the natural gas system far downstream from well sites.

Another means of estimating leakage rates, referred to as "top-down," measures methane in the

Fracking often introduces heavy industrial activity, and pollution, into rural areas.
PHOTO: U.S. Geological Survey.

atmosphere, using collection tools placed on towers, airplanes, or on cars doing drive-by surveys where oil and gas extraction and processing are occurring. Scientists then interpret the resulting data in light of other data gathered (wind patterns, industry operation levels, other sources of methane release such as agriculture, etc.) to model how much methane is attributable to oil and natural gas sector activity. These modeling-based studies are considered to have high external validity, that is, their results can more readily be generalized to other fracking sites. However they have lower internal validity, in that multiple other factors can affect atmospheric methane levels, making it difficult to say that no other variables contributed to the result.

A ground-breaking study of natural gas leakage from production sites, conducted by a consortium that included the National Oceanographic and Atmospheric Administration, the Environmental Defense Fund, nine universities and two private entities, succeeded in 2015 in reconciling top-down (atmospheric) and bottom-up (source-specific) estimates of methane leakage. That study, which examined the Barnett Shale oil- and gas-producing region of Texas, one of the nation's major natural gas production areas, used aircraft to capture atmospheric samples from production, processing, and distribution sources. It concluded among other things that methane emissions from oil and gas operations exceeded those reported by government inventories, showing results fully 90 percent higher than estimates based on the U.S. Environmental Protection Agency (EPA)'s Greenhouse Gas Inventory.[9]

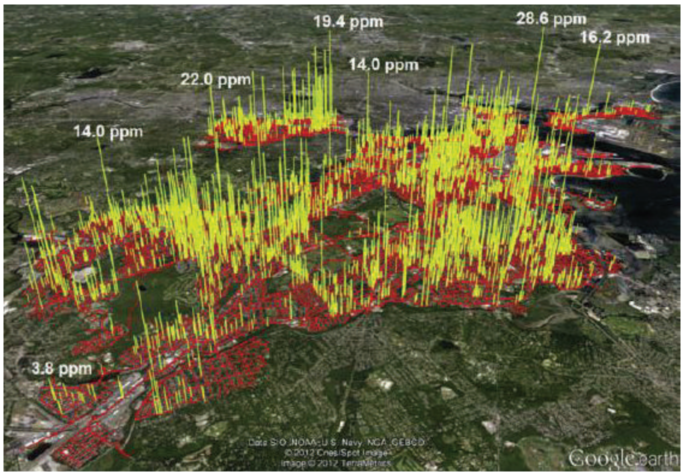
Active well sites are not the only source of leakage; methane also escapes from abandoned wells. Neither the EPA nor any equivalent state agency monitors methane leaking from abandoned wells,[10] yet studies indicate that three million abandoned wells exist[11] and that their leakage rates increase with age. A study conducted by an oil and gas company found that about five percent of natural gas wells leaked immediately; 50 percent were leaking after 15 years, and 60 percent after about 30 years.[12] As the wells constructed in the recent fracking boom begin to age, they will continue to add to global warming.

Flaring of methane from a fracking well.

How high, then, is the level of methane leakage from production sites? A 2014 study used satellite data to quantify fugitive emissions from the Bakken and Eagle Ford shale formations; it estimated their leakage rates at roughly 10.1 and 9.1 percent respectively. The study noted that those rates of leakage "call… into question" the climate benefit of natural gas use.[13]

METHANE LEAKAGE FROM INFRASTRUCTURE

Methane leakage also occurs across the natural gas supply chain, including processing, transport, storage facilities and final distribution. Gas escapes from the processing plants that remove impurities and from the compressors that pressurize the pipes to keep gas flowing; in fact, a study in Texas' Barnett Shale found that methane emissions from compressor stations were substantially higher than from well pads.[14] Another study of the Barnett Shale found methane emissions from natural gas processing plants and a compressor

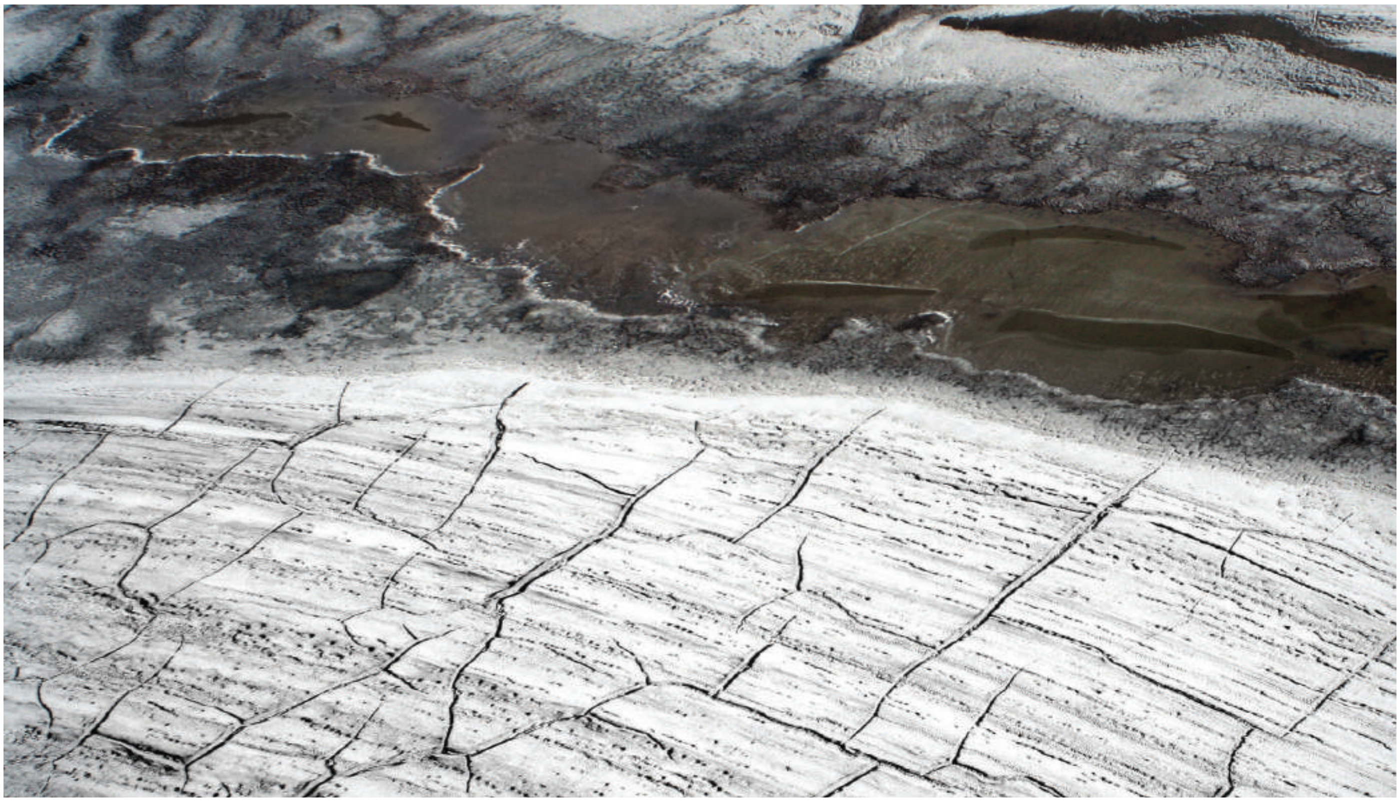


Methane leaks in the city of Boston, shown as concentrations (in parts per million) SOURCE: Reprinted from Environmental Pollution, Vol 173, Nathan G. Phillips et al., Mapping urban pipeline leaks: Methane leaks across Boston, 1-4, Copyright (2013), with permission from Elsevier.

station in the field were 3.2 to 5.8 times higher than estimates based on the U.S. EPA Greenhouse Gas Reporting Program, where large-scale industry sources are required to self-report emissions.[15]

Natural gas also leaks from pipelines. According to a report by the EPA's Office of Inspector General, the EPA acknowledged in 2012 that pipeline leaks "accounted for more than 13 million metric tons of carbon dioxide equivalent emissions" — at that time, more than 10 percent of total methane emissions from natural gas systems in the U.S.[16] Scientists measured methane leakage from distribution pipes under the streets of Boston and noted in January 2016 that of 100 natural gas leaks surveyed, 15 percent qualified as "potentially explosive," adding, "All leaks must be addressed, as even small leaks cannot be disregarded as 'safely leaking.'"[17] A study conducted in the Boston area in 2015 found that methane emissions from distribution pipelines and end use were two to three times greater than had been predicted by existing inventory methodologies and industry reports. The authors noted that areas that consume natural gas, as distinct from those that produce it, "may…represent areas of significant resource loss" and that the many leaks present in the Boston area "contribute[d] significantly to the total CH_4 source."[18] The same study of "downstream" methane emissions in Boston (transmission, distribution and end use) found that gas escaped at an average loss rate between 2.1 and 3.3 percent — more than twice as high as inventory data suggested.

Finally, natural gas storage facilities have proven also to leak. A massive leak at the Aliso Canyon natural gas storage facility near Los Angeles, California remained uncontrolled between October 2015 and February 2016, emitting more



Permafrost thawing in the Artic Circle. PHOTO: Brocken Inaglory

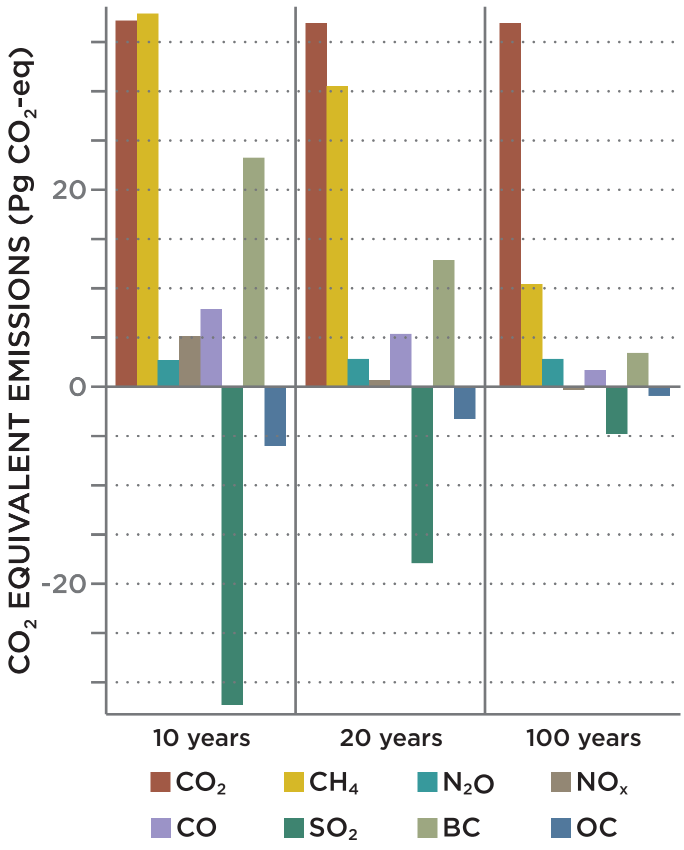
than 100,000 tons of methane into the air[19] — an amount estimated to equal the annual greenhouse gas emissions from over half a million cars.[20] It was the worst methane leak in U.S. history[21] and created a plume detectable from outer space.[22] In response, Congress passed the first federal legislation requiring regulation of underground natural gas storage facilities. It obligates the Pipeline and Hazardous Materials Safety Administration to develop regulations for gas storage facility construction and operation.[23]

HOW MUCH LEAKAGE OVERALL?

While the rate of methane leakage continues to be debated, the trend in research findings points to higher, not lower, rates of leakage. Earlier studies estimated that as little as 1.2 percent of the total methane output generated by the natural gas industry leaked into the atmosphere, with EPA and industry findings generally falling on the low side of the leakage rate spectrum. This however was widely disputed, with the EPA's own inspector general stating in 2014 that the EPA had not placed enough focus on the issue and was using outdated information in its analyses.[24] The EPA later revised upwards its estimates of 2014 life cycle methane emissions from the oil and gas industry, considered together, by 34 percent.[25] A 2016 study by Cornell University researcher Robert Howarth, calculating that transport, storage, and distribution systems added a 2.5 percent emission rate to the leakage at the point of extraction, concluded that on average 12 percent of the methane produced by fracking is lost by leaking into the atmosphere.[26]

How much methane leakage can the planet absorb without driving us to the tipping point? It was estimated in 2012 that the climate benefit of switching from coal-fired to gas-fired power plants can be achieved only if total natural gas leakage is below a threshold of 3.2 percent.[27] Howarth in 2014 proposed a comparable if slightly lower threshold of below 2.4 to 3.2 percent leakage.[28] To achieve those rates, the natural gas industry would have to attain far greater levels of methane capture, leak repair, and phase-out of blowdowns, flaring and other methane-emitting techniques than are now practiced.

CURRENT GLOBAL GREENHOUSE GAS EMISSIONS



Current global greenhouse gas emissions, as estimated by the IPCC, weighted for three different global warming potentials and expressed as carbon dioxide equivalents. At the 10-year time frame, global methane emissions expressed as carbon dioxide equivalents actually exceed the carbon dioxide emissions.
SOURCE: IPPC

Whether that can be achieved remains to be seen. One study, based on data and commentary from oil and gas producers and other industry sources, suggests that as much as 40 percent of fugitive emissions could be halted at minimal cost.[29] The EPA for its part in 2016 introduced regulations to reduce methane leaks from new, modified or reconstructed natural gas operations; it planned to propose similar regulations for existing sources in 2017. However, the new political environment places in doubt further regulation of the gas and oil industry. And even the Obama Administration's goal of cutting methane emissions from the industry by 40 to 45 percent[30] might not have been sufficient. Too little is known about actual leakage levels and their implications. How much methane leaks: 9.3 percent? 12 percent? How great is the actual level of methane production going to be? And how low do leakage rates need to be? A 40 percent reduc-

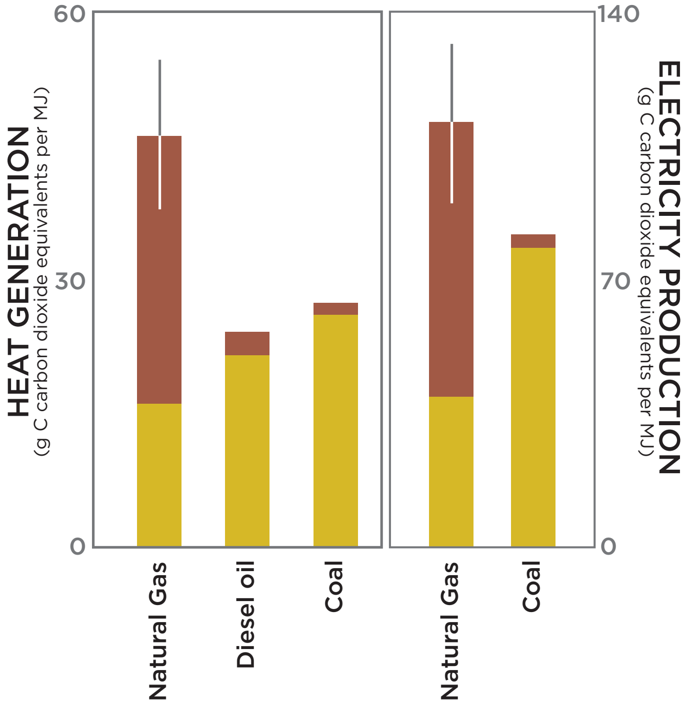
tion in a 12 percent industry leakage rate may not be sufficient for climate safety.

NATURAL GAS OR COAL?

What do these numbers imply about the climate benefits of replacing coal with natural gas to generate electricity? Scientists disagree. Two 2011 studies concluded that "the substitution of gas for coal as an energy source results in increased rather than decreased global warming for many decades..."[31] and that, "Compared to coal, the footprint of shale gas is at least 20 percent greater and perhaps more than twice as great on the 20-year horizon" and over a 100-year timeframe, comparable to coal.[32] A 2014 study found that over the 40-year lifespan of a power plant, assuming equally efficient plants and a low 2 percent methane leakage rate, methane and coal were roughly equal in their greenhouse emissions. Even methane leakage rates of 5 or 6 percent could be offset by using a most-efficient (60 percent) gas-burning power plant versus a merely typically efficient (34.3 percent) coal plant. Over a 100-year timespan, because of methane breakdown in the atmosphere, the study found that the warming effect from coal-fired plants would "considerably exceed" that of natural gas plants, even if methane leaks reached 9 percent.[33] However, another study conducted the same year concluded that turning to natural gas would have little to no effect in reducing greenhouse gas emissions and might actually increase them. Based on simulations from five integrated assessment models, it found that a majority of the models actually reported a small increase in climate-warming effects associated with the increased use of abundant gas.[34] **In short, the comparison is complex, the timeframe matters, and consensus does not exist in the scientific community. But there is a larger point that needs to be made: Both of these fossil fuels increase climate change and harm human health. To protect health and for the wellbeing of society, we need to transition our energy system off both of them.**

Methane leakage is not the only factor that determines natural gas's contribution to climate change; the duration of our dependence on fossil fuels also needs to be considered. If natural gas replaces coal in electricity generation, then power plants will be built or converted that are likely to operate for 40 years. This would extend our use of fossil fuels — and thus our climate-damaging emissions — far beyond the point of sustainability. Not only that; "the expansion of natural gas risks a delay in the introduction of near-zero emission energy systems,"[35] reducing the market for renewable energy sources like wind and solar power, which emit virtually no greenhouse gases beyond the limited energy required for production and transportation. Thus the choices that we make today about whether to pursue or reject natural gas are, implicitly, choices about when and how quickly we transform our energy system from fossil fuels to cleaner, healthier renewable energy and energy efficiency.

COMPARISON OF GREENHOUSE GAS FOOTPRINTS



Comparison of the greenhouse gas footprint for using natural gas, diesel oil, and coal for generating primary heat (left) and for using natural gas and coal for generating electricity (right).

CLIMATE CHANGE EFFECTS ON HUMAN HEALTH

Climate change damages human health and well-being in many ways. These health impacts have been widely studied and documented, including multiple climate-related threats that are specific to the United States. Below is a summary of health threats from climate change that are anticipated to strike the United States, drawn from the 2014 "National Climate Assessment" conducted by the U.S. Global Change Research Program.[36]

CLIMATE CHANGE FACTORS	RESULTS	POTENTIAL HEALTH EFFECTS
EXTREME HEAT EVENTS	Heat waves.	Deaths from heat stroke and related conditions, cardiovascular disease, respiratory disease, and cerebrovascular disease. Increased hospital admissions for cardiovascular, kidney, and respiratory disorders.
HEAT, WILDFIRES, AIR STAGNATION	Air pollution: heat + certain chemicals in the atmosphere yield increased ground-level ozone; wildfires and air stagnation episodes increase particulate matter.	Diminished lung function, increased hospital admissions and emergency room visits for asthma, and increases in premature deaths.
MORE FROST-FREE DAYS, WARMER AIR TEMPERATURES	Increased CO_2 yields higher pollen concentrations, longer pollen seasons.	Increased allergic sensitizations and asthma episodes, loss of work and school days. Harder to control asthma.
EXTREME RAINFALL, RISING TEMPERATURES	Growth of indoor fungi and molds.	Increases in respiratory and asthma-related conditions.
RECORD HIGH TEMPERATURES INCREASE VULNERABILITY OF FORESTS TO WILDFIRE.	Higher air pollution, including particulate matter, carbon monoxide, nitrogen oxides, volatile organic compounds (ozone precursors).	More respiratory and cardiovascular hospitalizations, emergency department visits, medications dispensed for asthma, bronchitis, chest pain, chronic obstructive pulmonary disease (COPD), respiratory infections. Deaths.

CLIMATE CHANGE FACTORS	RESULTS	POTENTIAL HEALTH EFFECTS
HEAVY RAINFALL	Floods	Deaths, mostly due to drowning
	Floods carry disease agents	Waterborne disease outbreaks
	Water intrusion into buildings can increase mold	Asthma, coughing and wheezing, lower respiratory tract infections such as pneumonia
DROUGHT	Wildfires, dust storms, extreme heat events, flash flooding, degraded water quality, and reduced water quantity	Degraded air quality (see above); also, increased incidence of Valley fever. Flooding (see above).
WEATHER VARIABLES SUCH AS TEMPERATURE CHANGES	Weather variables can change the geographic range of disease hosts (vectors)	Possible exposure to vector-borne diseases including Lyme, dengue fever, West Nile virus, Rocky Mountain spotted fever, plague, and tularemia. Vector-borne diseases not currently found in the United States, such as chikungunya, Chagas disease, and Rift Valley fever, can also become threats.
EXTREME RAINFALL EVENTS, EXTREMELY LOW PRECIPITATION, HIGHER AIR AND WATER TEMPERATURES	Favorable conditions for the growth of pathogens of food-borne and water-borne diarrheal disease; increased human exposure.	Diarrheal diseases including Salmonellosis and Campylobacteriosis
COMBINED EFFECTS OF CHANGES IN RAINFALL, SEVERE WEATHER EVENTS, AND INCREASING TEMPERATURES	Some crop yields will decline, as will livestock and fish production. Decreased protein in crops such as barley, sorghum, and soy. Increases in weeds and crop pests may lead to greater use of insecticides, herbicides.	Food insecurity for groups with particular dietary patterns like Alaska Natives and for low-income people. Loss of nutrition. Increased exposure to toxic agricultural products.
EXTREME WEATHER (e.g. hurricanes, floods, heat waves, wildfires)	Abnormal events increase mental health and stress-related disorders.	High levels of anxiety and post-traumatic stress disorder. Adverse birth outcomes including preterm birth, low birth weight, and maternal complications. Increases in suicide rates.

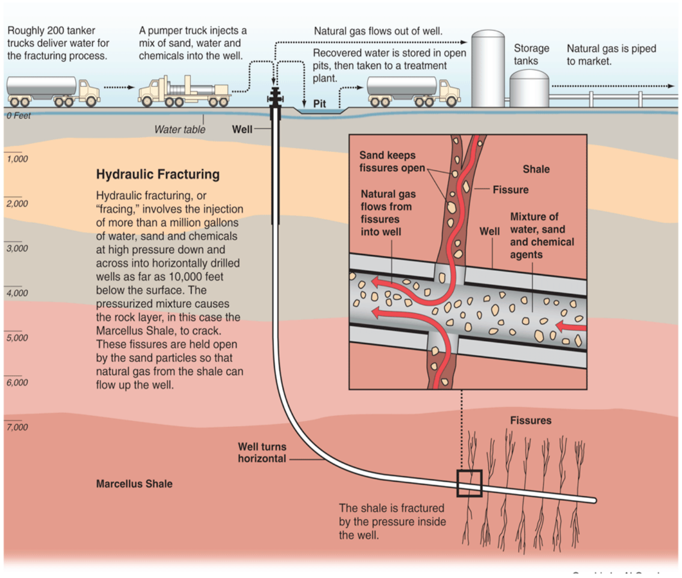
HEALTH EFFECTS OF HYDRAULIC FRACTURING (FRACKING)

Fracking* is a technique for extracting natural gas from deep underground bands of shale or other porous rock. Designed to extract previously untapped gas reserves, it involves pumping a highly pressurized mixture of chemicals and water deep into the earth to fracture the underlying rock formations. Many of the chemicals associated with fracking cause cancer, are endocrine-disruptive, or are otherwise toxic.[37]

The natural gas boom of the past 15 years is unprecedented, bringing over 15 million Americans into close proximity with this heavy industry[38] and resulting in increased human exposure to toxic substances. A growing body of scientific evidence links fracking to health effects ranging from headaches and nosebleeds to asthma exacerbations, birth defects and premature births. More than 900 peer-reviewed publications[39, 40] provide evidence of environmental, health, and societal effects of fracking.

FRACKING, HEALTH, AND AIRBORNE EMISSIONS

Fracking operations release toxic gases, including proven human carcinogens and potent toxicants of the nervous system. Among the most dangerous gases are certain volatile organic compounds (VOCs), which are released at each stage of fracking, from extraction to delivery.[41] VOCs commonly associated with fracking operations include the BTEX complex (benzene, toluene, ethylbenzene and xylene), which can cause cancer, affect the nervous system, or cause birth defects. (See chart.) A study by the University of Colorado Denver School of Public Health documented dangerous airborne levels of benzene near hydraulic fracturing operations as well as elevated risks of cancer for residents living within a half-mile of a



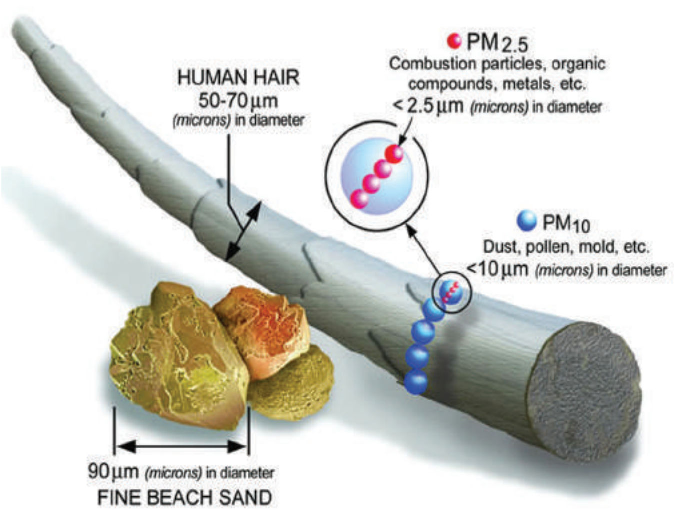
Hydraulic Fracking. ILLUSTRATION: Al Granberg

* Subsequent to this reference, we will use the term "fracking" to refer both to the process of fracturing the rock formations and to the associated operations that extract, process and transport natural gas. This encompasses land clearing, well drilling, construction of the well casing, flaring, wastewater extraction and storage, processing, compression, disposal of wastes, and natural gas transportation and distribution.

drilling site.[42] Ambient air testing near gas drilling operations in northern Texas found excessive amounts of benzene and of carbon disulfide, an extremely high-risk pollutant with "disaster potential" as categorized by the Texas Commission on Environmental Quality.[43]

In addition to being toxic, VOCs form ground-level ozone, also known as smog, when they mix with the nitrogen oxides from diesel-fueled trucks and equipment at fracking sites. Exposure to ground-level ozone can cause irreversible damage to the lungs[44] and significantly increase the chance of premature death.[45] VOCs and ozone pollution have been detected at dangerous levels at fracking sites, even in rural areas not usually associated with air pollution. Uintah County, Utah, home to one of the highest-producing oil and gas fields in the U.S., has experienced dangerously high levels of VOCs and ozone.[46] For parts of 2011, the level of ozone pollution in rural Wyoming's gas drilling areas exceeded that of Los Angeles and other major cities.[47]

Another study identified significant amounts of over 40 harmful chemicals in the air near drilling sites in Colorado.[48] While none were detected at levels above EPA limits, that study and others have noted that the EPA's ambient air quality standards may not be strict enough.[49] They do not fully account for long-term health effects of chemicals,[50] for the risks of episodic spikes in contaminant levels,[51] or for the enhanced risks to espe-



Relative sizes of particulate matter. ILLUSTRATION: EPA

AIR CONTAMINANTS ASSOCIATED WITH HYDRAULIC FRACTURING

BENZENE	Known carcinogen. May cause anemia; can lessen white blood cell count, weakening the immune system.[58] Prolonged exposure may result in leukemia, reproductive and developmental disorders, and other cancers.[59] There is no known safe level for air exposure.[60]
TOLUENE	Long-term exposure may affect the nervous system and cause miscarriages and birth defects.[61]
ETHYL-BENZENE	Long-term exposure may result in blood disorders.[62]
XYLENES	Short-term exposure to high levels may cause irritation of the nose and throat, nausea, vomiting, and neurological effects. Long-term exposure at high levels may affect the nervous system.[63]
NITROGEN OXIDES	Decrease oxygen absorption and weakens the lungs. Short-term exposure aggravates asthma. Contribute to the formation of ground-level ozone and particulate matter.[64, 65]
METHANE, ETHANE, PROPANE	May cause rapid breathing and heart rate, clumsiness, emotional upset. At greater exposure, may cause vomiting, collapse, convulsions, coma and death.[66]
FORMALDE-HYDE	A known carcinogen.[67] Can cause permanent and irreversible damage to the lungs.
SULFUR DIOXIDE	A major contributor to acid rain.[68] Can cause coughing, wheezing and shortness of breath and worsen asthma[69] and destabilize heart rhythms.[70] It is linked to bronchial reactions, reduced lung function and premature death.[71]

Three Brothers Compressor Station, Marcellus Shale, Atlasburg, Pennsylvania. PHOTO: MarcellusAir

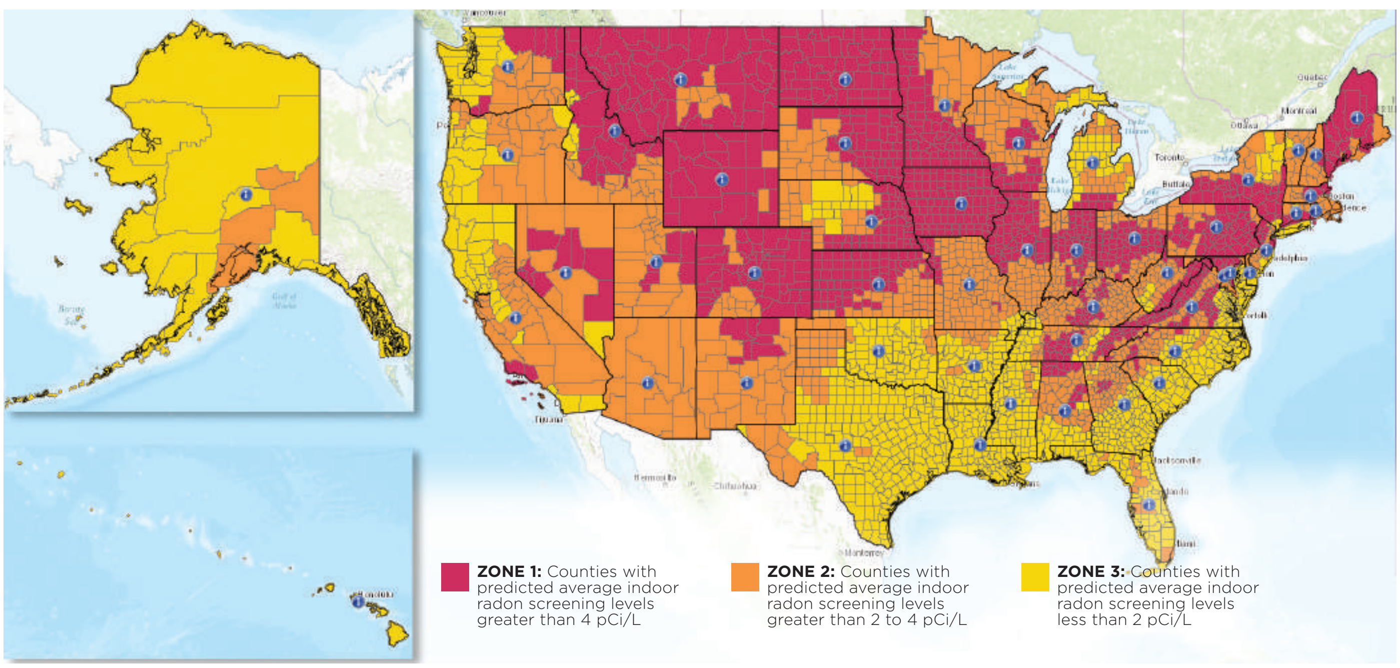
cially sensitive populations,[52] such as pregnant women, young children and the elderly.

Particulate matter is another fracking-related health hazard. Particulate matter is generated by the thousands of truck trips necessary for transporting fracking materials and the diesel motors operated on fracking sites and in many compressor stations. Studies have shown that inhalation of particulate pollution causes decreased lung function, aggravated asthma symptoms, nonfatal heart attacks, and high blood pressure.[53] Long-term repeated exposure is associated with cardiovascular disease and death.[54] Children are particularly vulnerable to particulate pollution; they may suffer decreased lung function, worsening asthma symptoms, and chronic bronchitis.[55] Rates of preterm births, low birth weight, and infant mortality are higher in communities with high particulate levels.[56] Exposure to particulate matter is also associated with increased school absences, emergency room visits and hospital admissions.[57]

Fracking for natural gas may also bring radioactive substances to the surface.[72] Some shale formations — notably the Marcellus — contain large amounts of naturally occurring radon gas as well as other radioactive elements. Radon is the leading cause of lung cancer among non-smokers and the second leading cause among smokers; the EPA attributes 21,000 lung cancer deaths per year on a nationwide basis to radon exposure.[73] Radon has a short half-life (3.8 days), but generates radioactive decay products, primarily polonium and lead, with longer half-lives: 22.6 years and 138 days, respectively. Polonium and lead have both been found to accumulate along the interior of natural gas pipes and related infrastructure.[74]

FRACKING, HEALTH, AND WATER CONTAMINATION

Fracking operations consume and contaminate enormous quantities of water. Hydraulic fracturing fluid is highly toxic to human and animal life, as



Radon Map of the United States by county. ILLUSTRATION: EPA

"many of the chemicals… should not be ingested at any concentration."[75] According to a 2011 Congressional report, 29 of the known substances most commonly used in fracking are dangerous enough that they would be regulated under the Safe Drinking Water Act or the Clean Air Act, if the 2005 Energy Policy Act had not exempted fracking from these fundamental environmental protection laws.[76] In fracking, these chemicals are mixed with huge quantities of water. In order to fracture a single well site, natural gas companies typically use over four million gallons of water — an amount equivalent to what 11,000 American families use in a day.[77] Such intensive water use places hydraulic fracturing in competition with other consumers of water including households, agriculture, industry, and recreation, and has become an issue in states like California, which is experiencing a historic drought. Nearly half of all fracking operations occur in areas with high or extremely high water stress.

An estimated 20 to 40 percent of water used in fracking subsequently comes back up to the surface, where it is classified as wastewater.[78] Fracking wastewater consists of a mix of withdrawn fracking fluids with naturally occurring brines — waters that contain high levels of salts as well as toxic levels of elements like barium, arsenic and radioactive radium, brought to the surface from deep underground.[79, 80] Oil and gas operations in the U.S. produce more than two billion gallons of fracking wastewater a day, and it is generally so severely contaminated that conventional water treatment facilities cannot purify it.[81] Regardless, fracking wastewater is categorized by the EPA as "special wastes" and as such is exempted from federal hazardous waste regulation under the Resource Conservation and Recovery Act (RCRA). Wastewater spills are a serious problem. The Associated Press (AP) analyzed data from leading oil- and gas-producing states and found that more than 180 million gallons of wastewater spilled in 21,651 incidents over five years (2009-2014).

In California, fracking wastewater from gas and oil extraction is sometimes used to irrigate crops, posing a risk of contamination of groundwater.[82] In addition, the state stores almost 60 percent of its fracking wastewater in unlined open-air pits.[83] Unlined wastewater pits containing oil field (not gas) wastewater in Kern County, in California's agricultural Central Valley, were reported to have contaminated groundwater with salt, boron and chloride.[84] Concerns were raised that these contaminants could eventually make their way into the Kern River, which is used for irrigation and drinking water.

Living close to fracking operations increases the risk of premature birth and congenital heart defects.

More than 95 percent of the nation's fracking wastewater is pumped into an estimated 30,000 injection wells, which serve as permanent storage sites.[85, 86] The U.S. Government Accountability Office (GAO) has found a lack of protection for drinking water sources from fracking injection wells. In 2014, GAO found that both short-term and long-term monitoring were lax, with the EPA neither mandating nor recommending a fixed list of chemicals for states to monitor, and record-keeping varying widely from state to state.[87, 88] In Stark County, North Dakota, a newspaper reporter's review of mechanical integrity tests revealed that state fracking waste injection wells were often leaky, and state regulators allowed injection into wells with documented structural problems even though the wells did not meet EPA guidelines for well bore integrity.[89]

Underground injection of large amounts of fracking fluids has been associated with earthquakes, particularly in Ohio[90] and Oklahoma,[91] including a destructive 5.7 magnitude quake in Oklahoma in 2011. A 2015 article in ***Science***, the magazine of the American Association for the Advancement of Science, noted that large areas of the U.S. that were "long considered geologically stable with little or no" earthquake activity have become seismically active. The article attributed this to "fluid-injection activities used in modern energy production."[92] The evidence for a causal link between earthquake swarms — repeated earthquakes in a relatively short period of time — and fracking wastewater injection into disposal wells led the Oklahoma Supreme Court to rule unanimously that homeowners can sue the oil and gas industry for injuries or property damage resulting from earthquakes.[93] Evidence now shows that the process of fracking itself can trigger earthquakes.[94]

The risk of drinking water contamination from fracking has been studied by governmental and private researchers. In June 2016, the EPA confirmed in a draft report that drilling and fracking activities had contaminated drinking water.[95] The report documented 457 fracking-related spills over six years; of those, 300 reached an environmental receptor such as surface water or groundwater. University of Texas researchers analyzing 550 water samples from public and private wells found widespread water contamination through-

Bakken injection site PHOTO: Joshua Doubek

out the heavily drilled Barnett Shale region of northern Texas. Contaminants included elevated levels of benzene and toluene and ten different metals.[96] In a study conducted in northeastern Pennsylvania, methane was detected in 82 percent of drinking water samples, with homes less than one kilometer from natural gas wells exhibiting average concentrations six times higher than those located far away. Ethane and propane were also found in drinking water, again with higher concentrations closer to fracking wells.[97]

Underground pathways to exposure can occur when hydraulic fracturing pipes carry fracking fluids through aquifers (naturally occurring reserves of underground water). When the cement well casings crack, fracking chemicals can contaminate the aquifer, which may be the sole water source supplying local wells. Such cracks may occur due to age; the Council of Canadian Academies identified the potential for leakage from aging wells as one of its top concerns about fracking. According to one expert panel, "the greatest threat to groundwater is gas leakage from wells from which even existing best practices cannot assure long-term prevention."[98]

DOCUMENTED HEALTH EFFECTS

Recent peer-reviewed medical studies have documented not only health risks, but actual associations between fracking operations and poor health outcomes. For example:

- A study published in *Epidemiology* in March 2016 examined electronic health record data on over 10,000 births in northern and central Pennsylvania. It found that expectant mothers living in the most active fracking areas were at greater risk of high-risk pregnancy and 40 percent more likely to give birth prematurely.[99] Preterm birth is the greatest contributor to infant death and is a leading cause of long-term neurological disabilities in children.[100]
- In a 2014 study of almost 25,000 births, congenital heart defects, and possibly neural tube defects in newborns, were associated with the density and proximity of natural gas wells within a 10-mile radius of mothers' residences in rural Colorado.[101]
- A study by University of Pennsylvania and Columbia University researchers found that fracking for gas and oil in Pennsylvania was associated with increased rates of hospitalization for cardiac, neurological, urological, cancer-related, skin-related problems. In the communities with the most wells, the rate of cardiac hospitalizations was 27 percent higher than in the control county.[102]

Air pollutants from fracking can cause permanent lung damage. Children are particularly vulnerable.

- Research published in the July 2016 *Journal of the American Medical Association* identified a statistical association between progressively worsening asthma symptoms and the patient's proximity to natural gas fracking operations.[103]

Health professionals warn that severe impacts like cancer, chronic respiratory illness, impaired cognition and neurologic impairment may appear in future years, given their long latency periods.[104,105,106] Full awareness and documentation of fracking's impacts on health have also been hindered by legal factors. "Gag rules" restrict doctors' rights to share information on patient exposures,[107] nondisclosure agreements are often part of private settlements between farmers and industry,[108] and some gas companies refuse to disclose the identity of chemicals they use in hydraulic fracturing. Laws passed by Congress in 2005 created the so-called "Halliburton loopholes," which exempted oil and gas companies from multiple federal regulations, including those that require monitoring and disclosure of chemicals in air and water.

FRACKING'S IMPACT ON ANIMALS AND AGRICULTURE

A small but growing body of scientific literature indicates that the health of farm animals and wildlife has been harmed by exposure to hydraulic fracturing fluid and air emissions. Animals may suffer higher levels of exposure, as they are outdoors more than humans and drink directly from ponds, streams and puddles. Additionally, their shorter reproductive cycles mean that toxics-induced infertility and other reproductive harms manifest sooner. Animals thus serve as "sentinels" of environmental contamination: if the environment is polluted, then animals may show the effects first.

Veterinarian M. Bamberger and R. E. Oswald, Cornell University professor of molecular medicine, were early investigators of impacts on farm animals. Based on their interviews with farmers near active fracking sites, they have documented stillbirths, near-immediate births and birth defects in cattle exposed to fracking wastes.[109] In an article published in 2012, they studied seven cattle farms in detail and found that "50 percent of the herd, on average, was affected by death

and failure of survivors to breed."[110] Other sources have also documented toxic effects of fracking fluid exposures. The Louisiana Department of Environmental Protection recorded a 2009 case of 17 cows dropping dead within hours after drinking spilled hydraulic fracturing fluid.[111] In 2010, 28 cows in Pennsylvania were quarantined after a leaking waste container left a puddle of hydraulic fracking fluid in their field.[112] A year later, the released cows appeared healthy, but gave birth to 11 offspring described as "dead or extremely weak," an outcome that the farm owner called "abominable."[113]

Air pollution associated with fracking sites has also been linked to health risks to farm animals. As early as 2001, thousands of cows in western Canada, one of the original epicenters of fracking, showed significantly increased rates of stillbirth and calf mortality linked to hydrogen sulfide released after natural gas extraction.[114] In Pennsylvania, increased fracking activity has been closely correlated with decreased dairy production.[115] While a direct link is difficult to prove, the correlation illustrates the need for greater caution about, and investigation into, adverse effects of fracking on farm animals.

Wildlife has also been shown to suffer harm from exposure to hydraulic fracturing chemicals. After a Kentucky fracking site spilled hydraulic fracturing fluid into a neighboring creek, "the discharges killed virtually all aquatic wildlife"[116] in the area. Fish that survived the spill developed gill lesions and suffered liver and spleen damage.[117]

The possibility that human health would be affected by consumption of food products from fish or farm animals exposed to fracking toxics is a topic in need of further study. In multiple known cases of chemical exposure, cows continued to produce dairy and meat for human consumption, although those products remained untested for chemical contaminants.[118]

The high-salinity wastewater that accompanies natural gas and oil from fracking wells has also been shown to harm agricultural lands. The Associated Press analysis of wastewater spills included an incident in Fort Stockton, Texas, where the local Groundwater Conservation District fined an energy company $130,000 for illegally dumping 3 million gallons of wastewater in pastures, and another where wastewater from pits seeped beneath a 6,000-acre cotton and nut farm near Bakersfield, California, and contaminated the groundwater. In that case, an oil company was ordered to pay $9 million to the farm owner, who had to remove 2,000 acres from production.[119]

In a field so relatively new, the scientific literature on health effects of fracking is not yet complete. Yet the evidence is substantial that fracking introduces toxic chemicals into the environment and brings up other dangerous substances from deep underground; that these dangerous substances are spread in the air and the water; and that people and farm animals suffer health effects, including birth defects, respiratory and cardiac effects, as a result.

HEALTH EFFECTS OF NATURAL GAS INFRASTRUCTURE

As natural gas is transported from its point of extraction to its point of ultimate use, it travels through an extensive infrastructure system. Gathering pipelines carry the gas to processing facilities, which remove impurities; from there, the gas travels through interstate transmission pipelines, often hundreds of miles, to distribution lines, service lines and end users.

Along the way, compressor stations keep the gas pressurized and moving, while specialized machinery removes water from the gas and cleans unwanted materials out of the pipelines. Storage facilities hold the gas before it is distributed. A growing body of scientific evidence documents leaks of methane, toxic volatile organic compounds and particulate matter throughout this infrastructure. These substances affect health, and the American Medical Association has recognized this by passing a resolution supporting "legislation that would require a comprehensive Health Impact Assessment regarding the health risks that may be associated with natural gas pipelines."[120]

HEALTH RISKS ASSOCIATED WITH PIPELINES

The integrity of transmission pipelines is assessed periodically, but the frequency of those assessments may vary from every seven to every 20 years.[121] In any case, leaks occur. The EPA acknowledged in 2012 that leaks from natural gas pipelines "accounted for more than 13 million metric tons of carbon dioxide equivalent emissions" and represented at that time more than 10 percent of total methane leaks from natural gas systems in the United States.[122] Pipelines may also emit gas during a "blowdown," which involves complete venting of the gases in a pipeline or compressor. Blowdowns are used to control pressure and empty the system and can be accidental or a scheduled part of maintenance. A typical blowdown releases a 90- to 180-foot plume of gas into the atmosphere and can last as long as three hours. Due to their intensity, blowdowns can emit pipeline contents at much higher concentrations than annual emissions data would suggest.[123] Thus, they hold the potential for exposing local residents to greater concentrations of toxic substances than

are reflected in the estimates of average exposures which are used in permitting decisions.

Methane leaks have also been documented from the urban pipelines that deliver natural gas to homes and other final users. Besides the "potentially explosive" leaks discovered in the streets of Boston, discussed in section 1,[124] scientists have measured methane leakage from distribution pipes in Washington, DC, where they mapped 5,893 leaks across 1,500 miles of road.[125] As is the case with blowdowns, toxic substances can escape from the pipelines along with the methane.

Natural gas pipelines have exploded and burned, damaging homes and businesses, at times leaving people injured or dead and overwhelming first responders. The U.S. Department of Transportation's Pipeline and Hazardous Materials Safety Administration (PHMSA) produces a report on "serious" pipeline incidents, those that include a fatality or injury requiring hospitalization. For the 20 years of 1996-2016, PHMSA recorded 858 serious incidents, with 347 fatalities (more than 17 each year) and 1,346 injuries.[126]

In 2012 a natural gas pipeline ruptured and burned in Sissonville, West Virginia. According to the Accident Report of the National Transportation Safety Board,

> *About 20 feet of pipe was separated and ejected from the underground pipeline and landed more than 40 feet from its original location. The escaping high-pressure natural gas ignited immediately. An area of fire damage about 820 feet wide extended nearly 1,100 feet along the pipeline right-of-way. Three houses were destroyed by the fire, and several other houses were damaged. There were no fatalities or serious injuries. About 76 million standard cubic feet of natural gas was released and burned.*[128]

The report stated that "[t]he outside pipe surface was heavily corroded near the midpoint of the rupture" and had suffered "more than 70 percent wall [thickness] loss."

Pipeline corrosion is a factor in some accidents. (See sidebar.) Aging pipes may account for some leaks; however, an analysis of federal data by the nonprofit Pipeline Safety Trust indicated that natural gas transmission lines installed in the 2010's are failing at a higher rate than those installed before 1940. The director of the National Transportation Safety Board's Office of Railroad, Pipeline and Hazardous Materials Investigations stated that "the rapid construction of pipelines in the U.S. is likely a contributing factor."[127]

Natural gas fires are intense and hard for firefighters to control. As such they can pose a danger to nearby vulnerable sites. For example, Spectra Energy's high-pressure Algonquin Incremental Market (AIM) natural gas pipeline will pass only 105 feet from vital structures at the aging Indian Point (NY) nuclear power plant and its 40 years' worth of spent fuel rods. Three New York counties — Rockland County, Westchester and Putnam — have adopted resolutions calling for a comprehensive assessment of the proposed project's potential health and safety impacts;[129, 130, 131] however, construction continues as of the time of this writing.

HEALTH RISKS ASSOCIATED WITH COMPRESSOR STATIONS

Compressors maintain the pressure that keeps gas flowing through the pipelines. Unlike drilling and fracturing activities, compressor stations operate 24 hours a day, year after year. Many are fueled by natural gas, and leak methane and carbon dioxide as they burn the gas. They also leak methane through compressor seals, valves, and connections and through the deliberate venting that is conducted during operations and maintenance. Compressor stations constitute "the primary source of vented methane emissions" in the transmission of natural gas.[132]

People living near compressor stations have experienced a range of symptoms ranging from skin rashes to gastrointestinal, respiratory, neurological and psychological problems.[133, 134] Air samples collected around compressor stations have shown elevated concentrations of many of the dangerous substances associated with fracked gas, including volatile organic compounds, particulate matter and gaseous radon, among others.[135] The federal

Aftermath of a 2012 natural gas explosion and fire.
PHOTO: National Transportation Safety Board.

Agency for Toxic Substances and Disease Registry (ATSDR) found that residents living near a natural gas compressor station in Washington County, PA were exposed to levels of chemicals in the air at which "some sensitive subpopulations (e.g. asthmatics, elderly) may experience harmful effects..."[136] ATSDR noted that the air quality studies conducted at the site "may not have adequately captured uncommon but significant incidents when peak emissions (e.g. unscheduled facility incidents, blowdowns or flaring events) coincide with unfavorable meteorological conditions (e.g. air inversion)."[137]

ATSDR also examined air quality near a natural gas compressor station in another Pennsylvania county, where they found fine particulate matter (PM2.5) at levels where long-term exposure can cause an increase in mortality, respiratory problems, hospitalizations, preterm births, and low birth weight; short-term exposure could harm sensitive populations like those with respiratory problems or heart disease.[138]

HEALTH RISKS ASSOCIATED WITH STORAGE FACILITIES

Awareness of potential health effects from natural gas storage facilities was greatly increased by the massive leak at the Aliso Canyon storage facility near Los Angeles, California in 2015-2016. The leak led to the relocation of thousands of families after area residents complained of headaches, nausea and nosebleeds.[139] Health effects from natural gas storage facilities will require further study. Scientists from Stanford and UCLA noted that the intermittent nature of data collection during the Aliso Canyon leak, plus the lack of scientific understanding of the long-term health effects of short-term exposures, left them unsure what to expect from residents' cumulative exposures to chemicals including benzene, hydrogen sulfide, and n-hexane, a neurotoxin.[140] The leak also spread particles of metal including barium, manganese, vanadium, aluminum, and iron in local homes, according to the Los Angeles County Health Department.[141]

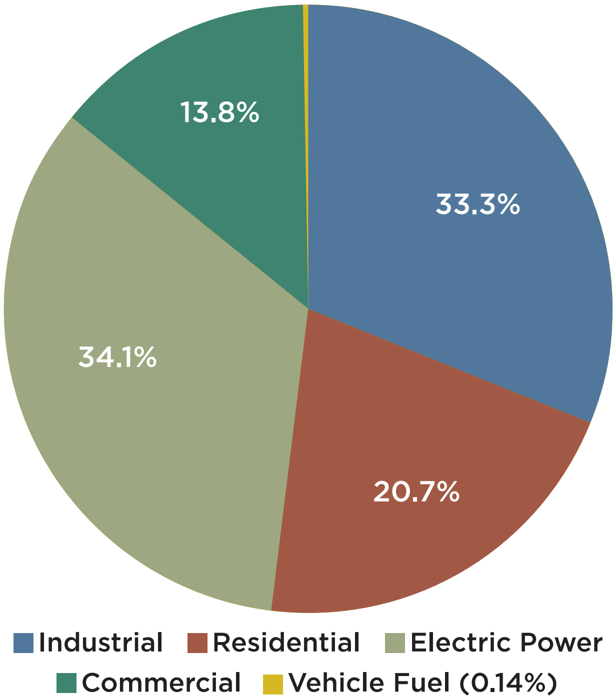
Aerial view of the Aliso Canyon gas leak, two months after the [methane leak] incident began. PHOTO: Roy Randall

CLEAN, HEALTHY ALTERNATIVES TO GAS

The decision to reject methane gas as a fuel can appear to be a hard one to make. There are several factors to consider besides the health impacts of energy and climate change. Energy generating capacity, the ability to meet needs such as heating and transportation, and the economic impacts of energy choices, must also be taken into account.

Methane is used for a variety of purposes, including industrial, commercial, and residential. (See chart.) It is also a source of jobs. If the United States does not use methane gas for those purposes, how will we meet those needs?

END USE OF NATURAL GAS—U.S. 2013



Electric power generation, industry, residences and commercial buildings were the major natural gas consuming sectors in the United States during calendar year 2013. Only 0.14 percent went to use as a vehicle fuel. Image by Geology.com using data from the United States Energy Information Administration.

CLEAN ENERGY AND EMPLOYMENT

Employment affects human health in a number of ways.[142] A good-paying, steady job can contribute to good health by making it easier for workers to buy ample and nutritious food, live in a safe and healthy neighborhood, and give their children access to a good education. Jobs are also the source of health insurance for more than half of the civilian workforce. Being unemployed has a direct negative impact on health. Laid-off workers are eighty-three percent more likely to develop a stress-related condition, such as stroke, heart attack, or heart disease; they also have higher levels of depression and anxiety. Thus, the employment capacity of the energy sector is a concern for physicians and other health and public health professionals. At the same time, we must note that not all jobs are created equal, and as the renewable and energy efficiency sectors become cost-competitive nationwide and these sectors expand to create more jobs, we must work with these sectors to ensure they are creating good jobs with family-sustaining wages and benefits. In addition, a just transition will need to ensure that workers who lose their jobs due to the clean-energy transition, such as those who work in the natural gas and coal industries, are provided with transitional support including job training opportunities.

Multiple sources concur that clean energy sources such as solar energy, wind energy and energy efficiency are already providing significant numbers of new jobs in the American economy. However, finding reliable government statistics about clean energy employment is difficult, due to varying definitions of the field, differing research methodologies, and the lack of a single body conducting relevant job surveys. For example, the U.S. Bureau of Labor Statistics does not provide employment statistics for individual industries such as solar and wind. We turn therefore to industry sources to provide job estimates.

OVERALL EMPLOYMENT IN RENEWABLE ENERGY

According to the International Renewable Energy Agency (IRENA), renewable energy employment in the United States increased by six percent in 2015 to reach 769,000 jobs.[143] (IRENA does not include large-scale hydropower in their renewable power estimates; however they do utilize sources which may be renewable but are not clean from a health perspective, such as biomass.) This increase, IRENA noted, was driven by growth in the wind and solar industries.

SOLAR EMPLOYMENT

IRENA calculated solar industry employment in the U.S. to have grown during 2015 by almost 22 percent to reach 209,000 jobs.[144] This accords with the report of the Solar Foundation's *National Solar Jobs Census 2015*, which reported 208,859 U.S. solar workers and an annual growth rate of 20.2 percent.[145] IRENA observed that the U.S. solar industry grew 12 times as fast as overall job creation in the U.S. economy, surpassing employment levels in oil and gas extraction (187,200) and in coal mining (67,929). Most solar jobs are in solar photovoltaics; over half are installation jobs, and almost two thirds occur in the residential market. Given the U.S. Congress' extension of the federal Investment Tax Credit through 2021, continued fast growth of the industry is expected, especially in the utility-scale market, which is however less labor-intensive than the residential sector.

WIND EMPLOYMENT

AWEA, the American Wind Energy Association, reported that the wind industry supported 88,000 jobs at the start of 2016, an increase of 21 percent in a year.[146] They also reported that wind was the nation's leading source of new electricity generating capacity in 2015, outpacing natural gas as well as solar power with a rise in annual installations of 77 percent to reach 8.6 GW. They attributed the large gains in part to the Production Tax Credit (PTC), as wind project developers moved swiftly to complete projects by the end of 2016, the expected end of the PTC qualification period. Job growth in 2015 reflected wind project development and construction, manufacturing sector, and the employment of wind turbine technicians, the fastest-growing profession in the U.S., according to the Bureau of Labor Statistics as cited by AWEA.[147] Texas, Oklahoma, Iowa, Colorado and Kansas were the states with the highest numbers of wind energy employees. Jobs at wind farms, wind-related manufacturing facilities, or both, are now located in 70 percent of U.S. Congressional districts.[148]

ENERGY EFFICIENCY EMPLOYMENT

Energy efficiency jobs occur in five distinct sectors: appliances, including large appliances and lighting efficiency; buildings, including both the green building sector and home and other building retrofitting; public transportation; smart grid and demand management; and vehicles, including electric and hybrid vehicle manufacturing and vehicle fuel efficiency manufacturing projects.[149] While solar and wind energy jobs are perhaps more visible, employment in the energy efficiency sector accounts for roughly four times as many jobs as do solar and wind, according to the American Council for an Energy-Efficient Economy (ACEEE). They estimated there to be 830,000 energy efficiency jobs in the United States as of 2010, and predicted that employment in the sector was increasing at a three percent annual rate, as cited by the Environmental and Energy Study Institute.[150] ACEEE is currently working on a new estimate for U.S. energy efficiency jobs.

COST COMPARISON TO COAL AND GAS INDUSTRIES

Compared to the capital investment required to produce clean energy, it takes a lot more capital to mine fossil fuels, build generating plants and pay on an on-going basis for the fuel. With renew-

able energies, capital costs occur upfront. Over a longer timeframe, wind and solar are cheaper to produce than coal, and wind is cheaper than natural gas. This is in part because wind and solar (and efficiency) have no fuel costs. In addition, states that don't have their own gas or coal production facilities must spend dollars outside the state to import fuel and are dependent on future pricing. Furthermore, clean energy results in significantly high levels of employment, and the jobs they generate tend to be local, keeping money in the local economy. Currently the coal and gas industries account for more jobs overall, but that is not surprising, given that they produce sixty percent of all the electricity while renewables are producing a mere fraction of that.

CLEAN ENERGY'S GENERATION CAPACITY

The amount of clean energy installed in the United States has been rising and prices have been dropping for renewable energy. In 2015, wind power generated 4.7 percent of total U.S. electricity generation, solar power 0.6 percent, and geothermal 0.4 percent.[151] Is it reasonable to look to these sources to power our nation?

Studies suggest that the answer is yes. While renewable energy (all sources) now account for about 13 percent of electricity generation,[152] an estimate by National Renewable Energy Laboratory estimated that renewable energy sources had in 2012 the potential to supply 482,247 billion kilowatt-hours of electricity annually.[153] Scientists and engineers have already prepared detailed plans to show how we as a nation will be able to meet all our energy needs using clean renewable sources and energy efficiency within 30 to 50 years.[154, 155] One of them, Mark Jacobson, a Stanford University professor of civil and environmental engineering, has developed "roadmaps" that lay out how the 50 U.S. states[156] and 139 nations[157] can transition to 100 percent renewable energy — primarily wind power, water power and sunlight — to meet all their purposes. His U.S. roadmaps envision 80 to 85 percent of existing energy being replaced by these sources by 2030 and 100 percent replaced by 2050. These plans show energy generation sufficient to meet the nation's needs not only for electricity, but also for transportation, heating, cooling, and industry. Some states are already on their way to meeting a substantial fraction of their energy needs from clean renewable energy. Iowa, for example, in 2015 generated 31 percent of its total electric energy generation from wind.[158]

If this can be done, why is it not being done? Several challenges still need to resolved: the intermittency of both solar and wind energy, the upfront capital costs, and management of a more complex electrical grid. At the same time, resolutions to several problems seem to be well on their way.

COSTS: Clean-energy technologies are developing rapidly and are now cheaper than natural gas on a per-kilowatt basis. Concerns over mechanisms to pay the upfront capital costs are being addressed in a variety of ways, such as production tax credits and rebates to homeowners for solar installation. Cost-leveling mechanisms also can work, as is demonstrated by the Regional Greenhouse Gas Initiative (RGGI), under which a cap is placed on the amount of carbon that can be emitted, and the permits to emit carbon are auctioned. This mechanism requires fossil fuels to pay for their carbon emissions, while energy sources that are essentially carbon-free are spared the expense.

POLICY: State policies calling for renewable portfolio standards (RPS) are also effective. This has been demonstrated in Michigan, for example, where the RPS of 10 percent by 2015 was achieved without significant electricity price increases for consumers and with net social benefit, due to reductions in coal burning and a resultant improvement in air quality and health.[159]

RECOMMENDATIONS

To protect human health from the increasing U.S. reliance on methane gas, the best response is twofold. While we still continue to use gas, we must reduce its negative consequences as quickly and effectively as possible: slash leakage, improve or replace leaking infrastructure, and reject practices that allow methane and pollutants to enter the environment.

These steps will help protect human health from the significant levels of water and air pollution and climate forcing we are now experiencing.

At the same time, we must step up the pace of our transition off methane gas, as well as coal and other fossil fuels, and onto renewable energy and energy efficiency. We present here several recommendations that are essential to health and to safeguarding a livable climate.

1. **Measure the global warming impacts of natural gas in the timeframe most likely to prevent irreversible changes.**
   a. The Environmental Protection Agency, Bureau of Land Management and Department of Energy must use the 20-year framework for calculating the global warming potential of methane in the atmosphere, in order to accurately reflect methane's potency in accelerating climate change. Methane over its first 20 years in the atmosphere is 86 times more potent than carbon dioxide.
   b. Methane leakage must be accurately measured on a regular basis across the entire natural gas production process, including extraction, processing, transport, storage and distribution.
   c. Calculate methane leakage at 10 percent, if not more, to reflect recent studies of leakage over the full methane gas life-cycle. This more-encompassing leakage rate makes it apparent that natural gas is as bad for the climate as coal, despite its lower production of carbon dioxide and sulfur dioxide at the point of combustion.

A researcher monitors air emissions near a Marcellus Shale gas well in Pennsylvania. PHOTO: Reid Frazier / The Allegheny Front

2. **Require federal, state and local governments to protect human health from gas-related operations.**
   a. Government plays an important role in protecting human health, and methane gas operations as currently conducted are harming human health. Federal, state and local governments should prioritize the protection of human health in their decisions concerning gas-related projects. Protection of health from the negative impacts of methane gas extraction should be a guiding principle in the relevant decision-making of federal decision-makers including the Environmental Protection Agency (EPA), Federal Energy Regulatory Commission (FERC), and

the Department of the Interior's Bureau of Land Management, as well as state, county and local governments.

b. State and local governments should use all the means at their disposal to protect human health from methane-related operations. State and local governments' right to establish laws and regulations to protect their citizens must be recognized and respected. Assure that state and local governments have the right to establish standards of health protection more stringent than those enacted by the federal government.

c. Ensure that all gas projects must comply with our bedrock environmental laws, including the Clean Water Act, Clean Air Act, Safe Drinking Water Act and the Resource Conservation and Recovery Act.

d. Require companies conducting hydraulic fracturing to fully and transparently declare the chemicals they use in those processes.

e. Oblige state or local governments to require an independent Health Impact Assessment (HIA) before making permitting decisions for a natural gas project. Every HIA should examine projected climate impacts, toxicity, radioactivity impacts, and social impacts.

3. Transition off of fossil fuels and promote the adoption of healthy, low-carbon energy sources.

a. Prioritize the development, adoption and use of low-carbon, low-polluting forms of energy. Promote clean energy technologies that are cost-effective and ready for immediate use, including wind, concentrated solar, roof-top solar, geothermal and heat pumps. Adopt more robust renewable portfolio standards.

b. Prioritize greater application of energy efficiency technologies in all sectors, including appliances, lighting, buildings, transportation and vehicles.

c. Support research and development where they are needed, especially energy storage technologies and construction of a "smart grid" that utilizes and moves energy efficiently.

d. Advocate for solar panel owners' right to send the energy they generate back to the electric company, and be credited for it, without facing charges or penalties ("net metering").

e. As we make the transition to clean energy, assure that the new jobs created in the U.S. economy are good, family-supporting jobs that provide competitive salaries and benefits, and that workers displaced from the fossil fuel industries are provided with job training.

These and similar steps will open the way to a healthy energy future, resulting in cleaner air and water, protecting us all from worsening climate change, strengthening the U.S. economy and creating hundreds of thousands of jobs. Our health and wellbeing, and ultimately our survival, depend on it.

ENDNOTES

1. Turner, A. J. et al. (2016) A large increase in U.S. methane emissions over the past decade inferred from satellite data and surface observations. Geophysical Research Letters, 43, 2218–2224, doi:10.1002/2016GL067987. http://onlinelibrary.wiley.com/doi/10.1002/2016GL067987/full
2. U.S. Energy Information Administration. (October 25, 2016) Electric Power Monthly, Table 1.1. https://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_1_01
3. IPCC, 2013: Summary for Policymakers. In: 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 University Press, Cambridge, United Kingdom and New York, NY, USA.
4. Wigley, Tom M. L. (October 1, 2011) Coal to gas: the influence of methane leakage. Climatic Change, Volume 108, Issue 3. http://link.springer.com/article/10.1007/s10584-011-0217-3
5. IPCC (2013). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf
6. Schaefer, K, et al. (2011). Amount and timing of permafrost carbon release in response to climate warming. Tellus, Series B. 63(2): 165-180
7. Schuur EAG, et al. (2008) Vulnerability of Permafrost Carbon to Climate Change: Implications for the Global Carbon Cycle, BioSci. 58(8):701- 714
8. Balcombe P, et al. (October 7, 2016) "The Natural Gas Supply Chain: The Importance of Methane and Carbon Dioxide Emissions." *ACS Sustainable Chemistry Engineering doi:* 10.1021/acssuschemeng.6b00144. http://pubs.acs.org/doi/abs/10.1021/acssuschemeng.6b00144
9. Karion, A., et al. (July 7, 2015) "Aircraft-based Estimate of Total Methane Emissions from the Barnett Shale Region." Environmental Science & Technology, Vol. 49 issue 13. http://dx.doi.org/10.1021/acs.est.5b00217
10. Kang, M., Kanno, C.M., Reid M.C, Zhang, X., Mauzerall, D.L., Celia, M.A., Chen, Y., and Onstott, T.C. (2014, December 8). Direct measurements of methane emissions from abandoned oil and gas wells in Pennsylvania. Proceedings of the Natural Academy of Sciences, electronic version ahead of print. doi: 10.1073/pnas.1408315111
11. Kang, M., Kanno, C.M., Reid M.C, Zhang, X., Mauzerall, D.L., Celia, M.A., Chen, Y., and Onstott, T.C. (2014, December 8). Direct measurements of methane emissions from abandoned oil and gas wells in Pennsylvania. Proceedings of the Natural Academy of Sciences, electronic version ahead of print. doi: 10.1073/pnas.1408315111
12. Brufatto, C. (2003). From mud to cement - Building gas wells. Oilfield Review, 15(3). Retrieved from http://www.slb.com/resources/publications/industry_articles/oilfield_review/2003/or2003aut06_building_gas_wells. aspx
13. Schneising, O., et al. (2014). Remote sensing of fugitive methane emissions from oil and gas production in North American tight geologic formations. Earth's Future 2(10), 548–558. doi: 10.1002/2014EF000265 http://onlinelibrary.wiley.com/doi/10.1002/2014EF000265/pdf
14. Lan, X., Talbot, R., Laine, P., & Torres, A. (2015). Characterizing fugitive methane emissions in the Barnett Shale area using a mobile laboratory. *Environmental Science & Technology*, 49, 8139-46. doi: 10.1021/es5063055
15. Lavoie, Tegan N. et al. (July 7, 2015) "Aircraft-Based Measurements of Point Source Methane Emissions in the Barnett Shale Basin." Environmental Science & Technology, Vol 9 issue 13. http://pubs.acs.org/doi/full/10.1021/acs.est.5b00410
16. U.S. Environmental Protection Agency Office of Inspector General. (2014, July 25). Improvements needed in EPA efforts to address methane emissions from natural gas distribution pipelines. Report No. 14-P-0324. Retrieved from http://www.epa.gov/oig/reports/2014/20140725-14-P-0324.pdf
17. Hendrick, M. F., Ackley, R., Sanaie-Movahed, B., Tang, X., & Phillips, N. G. (2016). Fugitive methane emissions from leak-prone natural gas distribution infrastructure in urban environments. *Environmental Pollution*, 213, 710-716. doi: 10.1016/j.envpol.2016.01.094
18. McKain, K.,et al. (February 17, 2015) Methane emissions from natural gas infrastructure and use in the urban region of Boston, Massachusetts. Proceedings of the Natural Academy of Sciences, vol. 112 no. 7. doi: 10.1073/pnas.1416261112
19. Conley, S., et al. (2016). Methane emissions from the 2015 Aliso Canyon blowout in Los Angeles, CA. *Science*. Advance online publication. doi: 10.1126/science.aaf2348
20. Phelan M. (February 23, 2016) "*Science*: 2015 Well Blowout Doubled Los Angeles' Methane Leak Rate." American Association for the Advancement of Science. https://www.aaas.org/news/science-2015-well-blowout-doubled-los-angeles-methane-leak-rate
21. Khan, A. (2016, February 25). Porter Ranch leak declared largest methane leak in U.S. history. *Los Angeles Times*. Retrieved from http://www.latimes.com/science/sciencenow/la-sci-sn-porter-ranch-methane-20160225-story.html
22. Thompson, D. R., et al. (2016). Space-based remote imaging spectroscopy of the Aliso Canyon CH4 superemitter. *Geophysical Research Letters* 43(12). doi: 10.1002/2016GL069079
23. Cama, T. (2016, June 22). Obama signs pipeline safety bill. *The Hill*. Retrieved from http://thehill.com/policy/energy-environment/284479-obama-signs-pipeline-safety-bill
24. U.S. Environmental Protection Agency Office of Inspector General. (2014, July 25). Improvements needed in EPA efforts to address methane emissions from natural gas distribution pipelines. Report No. 14-P-0324. Retrieved from http://www.epa.gov/oig/reports/2014/20140725-14-P-0324.pdf
25. Methane Pollution from the Oil & Gas Industry. "Oil and gas methane pollution by the numbers." http://www.methanefacts.org/files/2016/05/Methane-by-the-numbers-with-citations_051216.pdf
26. Howarth R.W. (October 8, 2015) "Methane emissions and climatic warming risk from hydraulic fracturing and shale gas development: implications for policy" in Energy Emission and Control Technologies. http://www.eeb.cornell.edu/howarth/publications/f_EECT-61539-perspectives-on-air-emissions-of-methane-and-climatic-warmin_100815_27470.pdf
27. Alvarez, R.A., et al. (February 2012) Greater focus needed on methane leakage from natural gas infrastructure. Proceedings of the National Academy of Sciences. http://www.pnas.org/content/109/17/6435.full
28. Howarth R.W. (April 2014) A bridge to nowhere: methane emissions and the greenhouse gas footprint of natural gas. Energy Science & Engineering. http://www.eeb.cornell.edu/howarth/publications/Howarth_2014_ESE_methane_emissions.pdf
29. ICF International. (March 2014) Economic Analysis of Methane Emission Reduction Opportunities in the U.S. Onshore Oil and Natural Gas Industries. https://www.edf.org/sites/default/files/methane_cost_curve_report.pdf
30. U.S. Environmental Protection Agency. EPA's Actions to Reduce Methane Emissions from the Oil and Natural Gas Industry: Final Rules and Draft Information Collection Request. https://www.epa.gov/sites/production/files/2016-09/documents/nsps-overview-fs.pdf
31. Wigley, T. (October 1, 2011) Coal to gas: the influence of methane leakage. Climatic Change, Volume 108, Issue 3. http://link.springer.com/article/10.1007/s10584-011-0217-3
32. Howarth R.W. et al. (2011) "Methane and the greenhouse-gas footprint of natural gas from shale formations A letter." Climatic Change. http://www.fe.doe.gov/programs/gasregulation/authorizations/2013_applications/sc_exhibts_13_116_118/Ex._102_-_Howarth_Methane_and_GHG_footpr.pdf
33. Zhang X. et al (November 26, 2014) Key factors for assessing climate benefits of natural gas versus coal electricity generation. Environmental Research Letters. doi:10.1088/1748-9326/9/11/114022 http://iopscience.iop.org/article/10.1088/1748-9326/9/11/114022
34. McJeon, H. et al. (2014). Limited impact on decadal-scale climate change from increased use of natural gas. Nature. October 15, 2014. http://dx.doi.org/10.1038/nature13837
35. Zhang X., et al. (April 2016) "Climate benefits of natural gas as a bridge fuel and potential delay of near-zero energy systems." Applied Energy, Volume 167. http://www.sciencedirect.com/science/article/pii/S030626191501243X
36. U.S. Global Change Research Program. 2014 National Climate Assessment. Washington, DC. http://nca2014.globalchange.gov/report/sectors/human-health
37. Colborn, T. et al., "Natural Gas Operations from a Public Health Perspective," *International Journal of Human and Ecological Risk Assessment*. 17:1039-1056 (2011). For an analysis of chemicals found in wastewater pits, see: http://endocrinedisruption.org/assets/media/documents/summary_of_pit_chemicals_revised_2-1-08.pdf
38. Gold, R., & McGinty, T., "Energy Boom Puts Wells in America's Backyards," *The Wall Street Journal*. 25 Oct. 2013.
39. Physicians, Scientists and Engineers for Healthy Energy. PSE Study Citation Database on Shale & Tight Gas Development. http://psehealthyenergy.org/site/view/1180
40. Concerned Health Professionals of New York and Physicians for Social Responsibility. 2016. Compendium of Scientific, Medical, and Media Findings Demonstrating Risks and Harms of Fracking (Unconventional Gas and Oil Extraction), 4th edition. http://concernedhealthny.org/wp-content/uploads/2016/12/COMPENDIUM-4.0_FINAL_11_16_16Corrected.pdf
41. Jerret, M. et al., "Long-Term Ozone Exposure and Mortality," *The New England Journal of Medicine*. 360:1085-95 (2009).
42. McKenzie L.M., et al., "Human health risk assessment of air emissions from development of unconventional natural gas resources," *Sci Total Environ*. (2012). doi:10.1016/j.scitotenv.2012.02.018
43. Wolf Eagle Environmental, "Town of DISH, Texas, Ambient Air Monitoring Analysis," (2009). <http://townofdish.com/objects/DISH_-_final_report_revised.pdf>.
44. Colborn, T. et al., "Natural Gas Operations from a Public Health Perspective," *International Journal of Human and Ecological Risk Assessment*. 17:1039-1056 (2011). For an analysis of chemicals found in wastewater pits, see: http://dx.doi.org/10.1080/10807039.2011.605662
45. Jerret, M. et al., "Long-Term Ozone Exposure and Mortality," *The New England Journal of Medicine*. 360:1085-95 (2009).
46. Helmig, D., "Highly Elevated Atmospheric Levels of Volatile Organic Compounds in the Uintah Basin, Utah," ***Environ. Sci. Technol.*** 48, 4707Ð4715. (2014). American Lung Association, "State of the Air 2014," (2014). http://www.stateoftheair.org/
47. Koch, W., "Wyoming's smog exceeds Los Angeles' due to gas drilling," *USA Today*. 9 March 2011.
48. Colborn, T., et al., "An Exploratory Study of Air Quality Near Natural Gas Operations," *Human and Ecological Risk Assessment*. 20 (1), pp. 86-105. (2014).
49. Brown, D., et al., "Understanding exposure from natural gas drilling puts current air standards to the test," *Reviews on Environmental Health*. Volume 0, Issue 0, March 2014.
50. Vandenberg, L.N., et al., "Hormones and Endocrine-Disrupting Chemicals: Low-Dose Effects and Nonmonotonic Dose Responses," *Endocrine Reviews*. (2012). 33(3):0000 – 0000.
51. Weinberger, B. et al. (April 23, 2016) ATSDR Releases Investigation of Pennsylvania Compressor Station. Southwest Pennsylvania Environmental Health Project.
52. Brown, D., et al., "Understanding exposure from natural gas drilling puts current air standards to the test," *Rev Environ Health*. (2014).

53. Brook R.D., Brook J.R., Urch B., Vincent R., Rajagopalan S., Silverman F. (2002). Inhalation of fine particulate air pollution and ozone causes acute arterial vasoconstriction in healthy adults. *Circulation, 105(13)*, 1534–1536.

54. Dockery D.W., Pope C.A., III, Xu X et al. (2003). An association between air pollution and mortality in six U.S. cities. *N Engl J Med*, 329(24), 1753–1759.

55. Gauderman W.J., Avol E., Gilliland F. et al. (2004). The effect of air pollution on lung development from 10 to 18 years of age. *The New England Journal of Medicine*, 351(11), 1057–1067.

56. Casey, J.A., Savitz, D.A., Rasmussen, S.G., Ogburn, E.L., Pollak, J., Mercer, D.G., & Schwartz, B.S. (2015). Unconventional natural gas development and birth outcomes in Pennsylvania, USA. *Epidemiology*. Advance online publication. doi: 10.1097/EDE.0000000000000387

57. Dominici F., Peng R.D., Bell M.L. et al. (2006) Fine particulate air pollution and hospital admission for cardiovascular and respiratory diseases. *JAMA, 295(10)*, 1127–1134.

58. National Institute for Occupational Safety and Health (NIOSH), "Emergency Preparedness and Response: Facts about Benzene," *Centers for Disease Control and Prevention*. 14 Feb 2013. https://emergency.cdc.gov/agent/benzene/basics/facts.asp

59. "Outdoor Air – Industry, Business, and Home: Oil and Natural Gas Production – Additional Information." *United States Environmental Protection Agency*. 19 Mar 2014. https://archive.epa.gov/airquality/community/web/html/oil-gas_addl_info.html

60. World Health Organization. Exposure to Benzene: A Major Public Health Concern. http://www.who.int/ipcs/features/benzene.pdf?ua=1

61. Agency for Toxic Substances and Disease Registry. Toxic substances portal: Benzene. Atlanta, GA: US Department of Health and Human Services, Agency for Toxic Substances and Disease Registry; 2011. Available at http://www.atsdr.cdc.gov/toxfaqs/tf.asp?id=38&tid=14 http://www.epa.gov/oaqps001/community/details/oil-gas_addl_info.html

62. "Outdoor Air – Industry, Business, and Home: Oil and Natural Gas Production – Additional Information." *United States Environmental Protection Agency*. 19 Mar 2014. https://archive.epa.gov/airquality/community/web/html/oil-gas_addl_info.html

63. "Outdoor Air – Industry, Business, and Home: Oil and Natural Gas Production – Additional Information." *United States Environmental Protection Agency*. 19 Mar 2014. https://archive.epa.gov/airquality/community/web/html/oil-gas_addl_info.html

64. EPA, "Nitrogen Dioxide: Health," Feb. 2013.

65. Agency for Toxic Substances and Disease Registry. Toxic substances portal: Nitrogen Oxides. Atlanta, GA: US Department of Health and Human Services, Agency for Toxic Substances and Disease Registry; 2011. Available at http://www.atsdr.cdc.gov/toxfaqs/tf.asp?id=396&tid=69

66. http://www.ccohs.ca/oshanswers/chemicals/chem_profiles/propane.html

67. Agency for Toxic Substances and Disease Registry. Toxic substances portal: Formaldehyde. Atlanta, GA: US Department of Health and Human Services, Agency for Toxic Substances and Disease Registry; 2011. Available at http://www.atsdr.cdc.gov/substances/toxsubstance.asp?toxid=39

68. Agency for Toxic Substances and Disease Registry. Toxic substances portal: Sulfur Dioxide. Atlanta, GA: US Department of Health and Human Services, Agency for Toxic Substances and Disease Registry; 2011. Available at http://www.atsdr.cdc.gov/toxfaqs/tf.asp?id=252&tid=46

69. Agency for Toxic Substances and Disease Registry. Public Health Statement for Sulfur Dioxide. Toxic Substances Portal, Sulfur Dioxide. https://www.atsdr.cdc.gov/ToxProfiles/tp116-c1-b.pdf

70. Agency for Toxic Substances and Disease Registry. Public Health Statement for Sulfur Dioxide. Toxic Substances Portal, Sulfur Dioxide. https://www.atsdr.cdc.gov/ToxProfiles/tp116-c1-b.pdf

71. Bascom, R., et al. (1996). Health effects of outdoor air pollution. American Journal of Respiratory and Critical Care Medicine, 153(1), 3-50.

72. Agency for Toxic Substances and Disease Registry. Environmental Health and Medicine Education. Atlanta, GA: US Department of Health and Human Services, Agency for Toxic Substances and Disease Registry; 2011. Available at http://www.atsdr.cdc.gov/csem/csem.asp?csem=8&po=5

73. U.S. Environmental Protection Agency. (2016) Radon: Health Risk of Radon. Available at https://www.epa.gov/radon/health-risk-radon

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

75. Colborn, T. et al., "Natural Gas Operations from a Public Health Perspective" *International Journal of Human and Ecological Risk Assessment* 17:1039-1056 (2011)

76. United States House of Representative Committee on Energy and Commerce Minority Staff Report, "Chemicals Used in Hydraulic Fracturing." April 2011. http://www.conservation.ca.gov/dog/general_information/Documents/Hydraulic Fracturing Report 4 18 11.pdf

77. Cusick, M., & Colaneri, K., "How Much Water Does It Take to Frack a Well?," *StateImpact Pennsylvania*. 2013. http://stateimpact.npr.org/pennsylvania/2013/03/12/how-much-water-it-takes-to-frack-a-well/

78. The Institute for Energy & Environmental Research for Northeastern Pennsylvania, Marcellus Shale Information Clearinghouse, What is flowback, and how does it differ from produced water? http://energy.wilkes.edu/pages/205.asp

79. The Institute for Energy & Environmental Research for Northeastern Pennsylvania, Marcellus Shale Information Clearinghouse, What is flowback, and how does it differ from produced water? http://energy.wilkes.edu/pages/205.asp

80. Jackson, R.B., Vengosh, A., Carey, J.W., R.J., Darrah, T.H., O'Sullivan, F., Pétron, G. (2014). The Environmental Costs and Benefits of Fracking. *Annual Review of Environment and Resources* (DOI: 10.1146/annurev-environ-031113-144051) Jackson et al. ARER Final 2014.

81. Jackson, R.B., et al., "The Environmental Costs and Benefits of Fracking," *Annual Review of Environment and Resources*. 39.1 (2014).

82. Shonkoff S.B.C. et al. (2015) Potential impacts of well stimulation on human health in California. Volume II, Chapter 6: An Independent Scientific Assessment of Well Stimulation in California. California Council of Science and Technology. http://ccst.us/publications/2015/vol-II-chapter-6.pdf

83. Shonkoff S.B.C. et al. (2015) Potential impacts of well stimulation on human health in California. Volume II, Chapter 6: An Independent Scientific Assessment of Well Stimulation in California. California Council of Science and Technology. http://ccst.us/publications/2015/vol-II-chapter-6.pdf

84. Cart, J. July 30, 2015. Central Valley board allows wastewater disposal to continue despite contamination. Los Angeles Times. http://www.latimes.com/local/california/la-me-oil-waste-pits-20150731-story.html

85. Jackson, R.B., Vengosh, A., Carey, J.W., R.J., Darrah, T.H., O'Sullivan, F., Pétron, G. (2014). The Environmental Costs and Benefits of Fracking. *Annual Review of Environment and Resources* (DOI: 10.1146/annurev-environ-031113-144051) Jackson et al. ARER Final 2014

86. "Ohio Earthquake Likely Caused by Fracking Wastewater." Scientific American. January 4, 2013. http://www.scientificamerican.com/article/ohio-earthquake-likely-caused-by-fracking/

87. U.S. Government Accountability Office. (2014). Drinking water: characterization of injected fluids associated with oil and gas production. GAO-14-657R. Retrieved from http://www.gao.gov/products/GAO-14-857R

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

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

90. "Ohio Earthquake Likely Caused by Fracking Wastewater." Scientific American. January 4, 2013. http://www.scientificamerican.com/article/ohio-earthquake-likely-caused-by-fracking/

91. "Injection Wells Spawn Powerful Earthquakes [Video]." Scientific American. July 12, 2013. http://www.scientificamerican.com/article/drilling-and-pumping-wells-spawn-powerful-earthquakes/

92. McGarr, A., et al. (February 2015) Coping with earthquakes induced by fluid injection. *Science*, Vol. 347, Issue 6224. http://science.sciencemag.org/content/347/6224/830

93. Oppel Jr., R.A. (2015, June 30). Oklahoma court rules homeowners can sue oil companies over quakes. *The New York Times*. https://www.nytimes.com/2015/07/01/us/oklahoma-court-rules-homeowners-can-sue-oil-companies-over-quakes.html

94. Skoumal, R. J., Brudzinski, M. R. & Currie, B. S. (2015). Earthquakes induced by hydraulic fracturing in Poland Township, Ohio. *Bulletin of the Seismological Society of America 105*(1). doi: 10.1785/0120140168

95. U.S. EPA. (2015) *Assessment of the potential impacts of hydraulic fracturing for oil and gas on drinking water resources* (External review draft). U.S. Environmental Protection Agency, Washington, DC. https://cfpub.epa.gov/ncea/hfstudy/recordisplay.cfm?deid=244651

96. Hildenbrand, Z.L., et al. (2015) A comprehensive analysis of groundwater quality in the Barnett Shale region. *Environmental Science and Technology, 49*. doi: 10.102./acs.est.5b01526

97. Jackson, R.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 no. 28, 11250-11255. (2013).

98. Council of Canadian Academies. (May 2014) Environmental Impacts of Shale Gas Extraction in Canada: The Expert Panel on Harnessing Science and Technology to understand the Environmental Impacts of Shale Gas Extraction. http://www.scienceadvice.ca/uploads/eng/assessments%20and%20publications%20and%20news%20releases/shale%20gas/shalegas_fullreporten.pdf

99. Casey J.A. et al. "Unconventional Natural Gas Development and Birth Outcomes in Pennsylvania, USA." Epidemiology, Volume 27, Issue 2. March 2016. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4738074/

100. Centers for Disease Control and Prevention. "Premature Death." http://www.cdc.gov/reproductivehealth/maternalinfanthealth/pretermbirth.htm

101. McKenzie, L. M., et al. (2014). Birth outcomes and maternal residential proximity to natural gas development in rural Colorado. Environmental Health Perspectives, 122, 412-417. doi: 10.1289/ehp.1306722

102. Jemielita T. et al, 2015. Unconventional gas and oil drilling is associated with increased hospital utilization rates. *PLoS ONE 10*, e0131093. doi: 10.1371/journal.pone.131093.

103. Rasmussen, SG, et al (September 2016). Association Between Unconventional Natural Gas Development in the Marcellus Shale and Asthma Exacerbations. Journal of the American Medical Association. JAMA Intern Med. 2016;176(9):1334-1343. doi:10.1001/jamainternmed.2016.2436

104. Finkel ML, Law A. (October 2016) The Rush to Drill for Natural Gas: A Five-Year Update. *American Journal of Public Health*. Am J Public Health. 2016 Oct;106(10):1728-30. doi: 10.2105/AJPH.2016.303398.

105. Macey, G.P., et al. Air concentrations of volatile compounds near oil and gas production: a community-based exploratory study. *Environmental Health*, 13, (82). Doi: 10.1186/1476-0669-13-82.

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

107. Tsou, W., "The Big Secret? Fracking Fluids," *Environmental Health Policy Institute* (2012).

108. Efstathiou, J., & Drajem, M., "Drillers Silence Fracking Claims With Sealed Settlements," *Bloomberg*. 6 June 2013.

109. Bamberger, M., & Oswald, R. E. (2014) The Real Cost of Fracking. Beacon Press, Boston.

110. Bamberger M. and Oswald R (2012). Impacts of Gas Drilling on Human and Animal Health. New Solutions, Vol. 22(1) https://www.ncbi.nlm.nih.gov/pubmed/22446060

111. Mall, A. August 26, 2009. "How toxic are hydraulic fracturing fluids? Ask Louisiana," *Switchboard: Natural Resource Defense Council Staff Blog*. http://switchboard.nrdc.org/blogs/amall/how_toxic_are_hydraulic_fractu.html

112. Thomson Reuters. July 1, 2010. "Pennsylvania quarantine cattle over gas drilling fluid," *Reuters*. http://www.reuters.com/article/2010/07/01/us-pennsylvania-natgas-cattle-idUSTRE66058L20100701

113. Phillips, S. Sept. 27, 2011."Burning Questions: Quarantined Cows Give Birth to Dead Calves." *NPR StateImpact*. http://stateimpact.npr.org/pennsylvania/2011/09/27/burning-questions-quarantined-cows-give-birth-to-dead-calves/

114. Waldner, C.L. et al., "Associations Between Oil- and Gas-Well Sites, Processing Facilities, Flaring, and Beef Cattle Reproduction and Calf Mortality in Western Canada," *Preventative Veterinary Medicine* 50 (July 19, 2001): 1–17.

115. Finkel et al. (2013)"Marcellus Shale Drilling's Impact on the Dairy Industry in Pennsylvania: A Descriptive Report," *New Solutions* 23(1): 189-201.

116. U.S. Fish and Wildlife Service, Office of Law Enforcement. *U.S. v. Nami Resources Company, LLC*. 2009. http://www.fws.gov/home/feature/2009/pdf/NamiInvestigation.pdf?

117. Papoulias, D.M., & Velasco, A.L. (2013)"Histopathological Analysis of Fish from Acorn Fork Creek, Kentucky, Exposed to Hydraulic Fracturing Fluid Releases," *Southeastern Naturalist*, Volume 12, Special Issue 4 (2013): 92–11

118. Bamberger, M., & Oswald, R. E. (2012) "Impacts of Gas Drilling on Human and Animal Health" *New Solutions* 22: 51-77.

119. Associated Press. (September 8, 2015) "AP exclusive: Drilling boom means more harmful waste spills." http://www.chicagotribune.com/news/nationworld/ct-drilling-harmful-waste-spills-20150908-story.html

120. American Medical Association. (2015). H-135.930 Protecting public health from natural gas infrastructure, Resolution 519, A-15.

121. PHMSA. Gas Transmission Integrity Management: Fact Sheet. U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration. https://primis.phmsa.dot.gov/gasimp/fact.htm

122. U.S. Environmental Protection Agency Office of Inspector General. (July 25, 2014). Improvements needed in EPA efforts to address methane emissions from natural gas distribution pipelines. Report No. 14-P-0324. https://www.epa.gov/sites/production/files/2015-09/documents/20140725-14-p-0324_0.pdf

123. New York State Madison County Health Department (2014). Comments to the Federal Energy Regulatory Committee concerning docket no. CP14-497-000, Dominion Transmission, Inc. https://www.madisoncounty.ny.gov/sites/default/files/publicinformation/madison_county_doh_comments_-_docket_no._cp14-497-000.pdf

124. Hendrick, M. F., Ackley, R., Sanaie-Movahed, B., Tang, X., & Phillips, N. G. (2016). Fugitive methane emissions from leak-prone natural gas distribution infrastructure in urban environments. *Environmental Pollution, 213*, 710-716. doi: 10.1016/j.envpol.2016.01.094

125. Jackson, R.B., et al. (January 16, 2014) Natural Gas Pipeline Leaks Across Washington, DC. Environmental Science & Technology. DOI: 10.1021/es404474x. http://pubs.acs.org/doi/abs/10.1021/es404474x

126. PHMSA. Serious Incidents. U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration. https://hip.phmsa.dot.gov/analyticsSOAP/saw.dll?Portalpages&NQUser=PDM_WEB_USER&NQPassword=Public_Web_User1&PortalPath=%2Fshared%2FPDM%20Public%20Website%2F_portal%2FSC%20Incident%20Trend&Page=Serious&Action=Navigate&col1=%22PHP%20-%20Geo%20Location%22.%22State%20Name%22&val1=%22%22

127. Smith, S. (September 9, 2015). As US rushes to build gas lines, failure rate of new pipes has spiked. *SNL Financial*. https://www.snl.com/InteractiveX/Article.aspx?cdid=A-33791090-11060

128. National Transportation Safety Board. 2014. Columbia Gas Transmission Corporation Pipeline Rupture, Sissonville, West Virginia, December 11, 2012. Pipeline Accident Report. NTSB/PAR-14/01. Washington, DC. http://www.ntsb.gov/investigations/AccidentReports/Reports/PAR1401.pdf

129. Rockland County Legislature. (2014, September 16). *Resolution No. 404 of 2014 urging that health, safety and planning concerns be addressed and mitigated in the Environmental Review and all other review processes before project permissions be granted for Spectra Energy's Algonquin Incremental Market (AIM) Natural Gas Pipeline, Compressor and Metering Stations Expansion Project.* https://sape2016.files.wordpress.com/2014/05/rockland-aim-resolution.pdf

130. Board of Legislators County of Westchester, State of New York. (2014, July 21). *Resolution RES-2014-80 Algonquin Incremental Marketing Project resolution.* https://sape2016.files.wordpress.com/2014/05/080414-wcbol-resolution-no-80-2014-requesting-due-diligence-on-environment-p.pdf

131. Putnam County Legislature. (2014, May 9). *Resolution #104, Resolution regarding the Algonquin Incremental Market (AIM) Project.* https://sape2016.files.wordpress.com/2014/05/putnam-county-resolutions-104-163-and-182-1.pdf

132. ICF International. (March 2014) Economic Analysis of Methane Emission Reduction Opportunities in the U.S. Onshore Oil and Natural Gas Industries. https://www.edf.org/sites/default/files/methane_cost_curve_report.pdf

133. Brown, D.R., Weinberger, C.I., Weinberger, B.I. (2015). Human exposure to unconventional natural gas development: A public health demonstration of periodic high exposure to chemical mixtures in ambient air. *Journal of Environmental Science and Health*, Part A, 50:5, 460-472, DOI: 10.1080/10934529.2015.992663. https://www.ncbi.nlm.nih.gov/pubmed/25734822

134. Southwest Pennsylvania Environmental Health Project (2015). Summary on compressor stations and health impacts. http://www.environmentalhealthproject.org/files/Summary%20Compressor-station-emissions-and-health-impacts-02.24.2015.pdf

135. New York State Department of Health. (2014). A public health review of high volume hydraulic fracturing for shale gas development. http://www.health.ny.gov/press/reports/docs/high_volume_hydraulic_fracturing.pdf

136. Agency for Toxic Substances and Disease Registry. (2016, January 29). *Health Consultation: Exposure Investigation, Natural Gas Ambient Air Quality Monitoring Initiative Brigich Compressor Station, Chartiers Township, Washington County, Pennsylvania.*

137. Agency for Toxic Substances and Disease Registry. (2016, January 29). *Health Consultation: Exposure Investigation, Natural Gas Ambient Air Quality Monitoring Initiative Brigich Compressor Station, Chartiers Township, Washington County, Pennsylvania.*

138. Agency for Toxic Substances and Disease Registry. (2016, April 22). *Health Consultation: Brooklyn Township PM2.5, Brooklyn Township, Susquehanna County, Pennsylvania.* U.S. Department of Health and Human Services, Atlanta, GA. http://www.atsdr.cdc.gov/HAC/pha/BrooklynTownship/BrooklynTwnsp_pm2-5_HC_Final_04-22-2016_508.pdf

139. Sewell, A. (March 18, 2016) "Porter Ranch residents displaced by gas leak have one more week to return home." Los Angeles Times. http://www.latimes.com/local/lanow/la-me-ln-porter-ranch-relocation-20160318-story.html

140. McKenna, P. (2016, February 18). What will be the health impact of 100+ days of exposure to California's methane leak? *InsideClimate News*. http://insideclimatenews.org/news/17022016/health-impacts-aliso-canyon-porter-ranch-methane-leak-california-socal-gas

141. Abram, S. (2016, July 13). SoCalGas slammed for poor cleanup of Porter Ranch homes. *Los Angeles Daily News*. http://www.dailynews.com/health/20160713/socalgas-slammed-for-poor-cleanup-of-porter-ranch-homes

142. Robert Wood Johnson Foundation. How Does Employment—or Unemployment— Affect Health? http://www.rwjf.org/content/dam/farm/reports/issue_briefs/2013/rwjf403360

143. International Renewable Energy Agency. (2016) "Renewable Energy and Jobs: Annual Review 2016." http://www.se4all.org/sites/default/files/IRENA_RE_Jobs_Annual_Review_2016.pdf

144. International Renewable Energy Agency. "Renewable Energy and Jobs: Annual Review 2016" IRENA. http://www.se4all.org/sites/default/files/IRENA_RE_Jobs_Annual_Review_2016.pdf

145. The Solar Foundation. National Solar Jobs Census 2015. http://www.thesolarfoundation.org/national/

146. American Wind Energy Association. (April 12, 2016) 'Wind rush' fuels hiring boom, delivers more consumer savings. http://www.awea.org/MediaCenter/pressrelease.aspx?ItemNumber=8736

147. Alvarez G. (January 8, 2016) Meet America's fastest growing profession: wind technician. Into the Wind: The AWEA blog. http://www.aweablog.org/meet-americas-fastest-growing-profession-wind-technician/

148. American Wind Energy Association. US wind power jobs hit record, up 20 percent in 2016. http://www.awea.org/MediaCenter/pressrelease.aspx?ItemNumber=8736

149. http://www.eia.gov/tools/faqs/faq.cfm?id=92&t=4

150. Environmental and Energy Study Institute. Fact Sheet: Jobs in Renewable Energy and Energy Efficiency (2015) http://www.eesi.org/papers/view/fact-sheet-jobs-in-renewable-energy-and-energy-efficiency-2015

151. Environmental and Energy Study Institute. Fact Sheet: Jobs in Renewable Energy and Energy Efficiency (2015) http://www.eesi.org/papers/view/fact-sheet-jobs-in-renewable-energy-and-energy-efficiency-2015

152. U.S. Energy Information Administration. Frequently Asked Questions. http://www.eia.gov/tools/faqs/faq.cfm?id=92&t=4

153. U.S. Department of Energy, National Renewable Energy Laboratory. (July 2012) "U.S. Renewable Energy Technical Potentials: A GIS -Based Analysis." Cited in Union of Concerned Scientists, Benefits of Renewable Energy Use. http://www.ucsusa.org/clean-energy/renewable-energy/public-benefits-of-renewable-power#.WE8_bLIrJ1t

154. Mark Z. Jacobson M.Z. et al. (October 24, 2016) 100% Clean and Renewable Wind, Water, and Sunlight (WWS) All-Sector Energy Roadmaps for 139 Countries of the World. http://web.stanford.edu/group/efmh/jacobson/Articles/I/CountriesWWS.pdf

155. Makhijani, A. (July 2007) Carbon-Free and Nuclear-Free: A Roadmap for U.S. Energy Policy. Institute for Energy and Environmental Research. http://ieer.org/wp/wp-content/uploads/2007/08/CFNF.pdf

156. Mark Z. Jacobson M.Z. et al. (2015) 100% clean and renewable wind, water, and sunlight (WWS) all-sector energy roadmaps for the 50 United States. Energy & Environmental Science, 2015, 8, 2093. http://web.stanford.edu/group/efmh/jacobson/Articles/I/USStatesWWS.pdf

157. Mark Z. Jacobson M.Z. et al. (October 24, 2016) 100% Clean and Renewable Wind, Water, and Sunlight (WWS) All-Sector Energy Roadmaps for 139 Countries of the World. http://web.stanford.edu/group/efmh/jacobson/Articles/I/CountriesWWS.pdf

158. Iowa Utilities Board. Wind-powered electricity generation in Iowa. https://iub.iowa.gov/wind-powered-electricity-generation

159. Mikalonis, Saulius. "Report measures impact of Renewable Portfolio Standard. Crain's Detroit Business. January 15,2016. Accessed Dec 16, 2016 http://www.crainsdetroit.com/article/20160115/BLOG103/160119927/report-measures-impact-of-renewable-portfolio-standard

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