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S. 585 American Natural Gas Security and Customer Protection Act

MPA in Environmental Science and Policy
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Disclaimer

This report is prepared for the summer semester course ENVP U9229 Workshop in Applied Earth Systems Management of MPA in Environmental Science and Policy program, Class of 2016. All information contained in this report is prepared from data and sources believed to be correct and reliable as of August 2015. The views, recommendations, and opinions in this report may not necessarily reflect those of Columbia University or any of its affiliates.

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Executive Summary

Since the early 2000s, the United States has been host to an unprecedented expansion in natural gas production from unconventional sources. The expansion has facilitated the realization of U.S. energy independence from foreign sources, extremely low domestic natural gas prices, and a desire by production companies to sell natural gas on global markets where prices per unit are considerably higher than domestic prices.

A combination of novel extraction techniques and political factors led to the expansion, starting with the innovative process of directional horizontal drilling. The coupling of horizontal drilling with the process of hydraulic fracturing has allowed access to previously unrecoverable natural gas from shale formations deep in the earth's lithosphere. In 2005, congress exempted natural gas extraction from traditional environmental regulations such as the Safe Drinking Water Act, Clean Water Act, and Clean Air Act. Expanded natural gas extraction has been accompanied by increasing concerns over the unregulated environmental impacts of extraction using hydraulic fracturing.

In an effort to address the implications of increasing exports, Senator Edward Markey introduced the American Natural Gas Security and Consumer Protection Act (S. 585) in 2015. The legislation requires the Secretary of Energy to define the public good in regards to increased pricing on US consumers, environmental impacts of extraction projects on local communities, and contributions of methane production to global climate change before authorizing natural gas exports.

The proposed act is a step in the right direction to account for the unregulated negative externalities associated with methane extraction via hydraulic fracturing. Aside from increases in consumer costs and threats to energy independence, the negative environmental impacts identified thus far effect hydrologic, lithospheric, and atmospheric earth systems. These effects present negative implications for human and ecosystem health in communities surrounding extraction sites, as well as detrimental contributions to global climate change.

This report will provide scientific analysis of the environmental problems associated with natural gas production, mainly problems associated with the hydraulic fracturing extraction process, and offer possible solutions to balance the economic benefits of increased natural gas benefits with the negative effects on human health and the environment.

1. Introduction

Natural gas first came under regulation in the U.S. under the Natural Gas Act of 1938. This legislation regulated interstate transmission of natural gas and established what would become the Federal Energy Regulatory Commission (FERC). In the 1990s improvements in directional drilling technology enabled intricate pathways into previously unreachable natural gas rich shale formations (Figure 1.1) and hydraulic fracturing facilitated release of the natural gas.

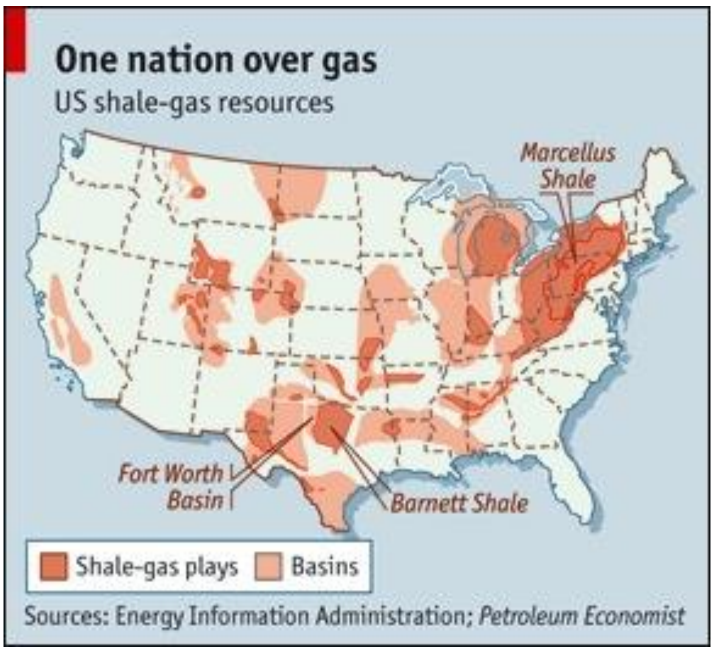

Figure 1.1: Map of natural gas containing shale formations in the U.S. in 2014.
Source: Energy Information Administration

In terms of cost, natural gas prices are currently declining. The comparison between natural gas and oil prices is illustrated in Figure 1.1. The prices of these two commodities are vastly different at the current juncture, signifying a potential move to natural gas energy sources instead of gasoline (as well as coal) in the future.

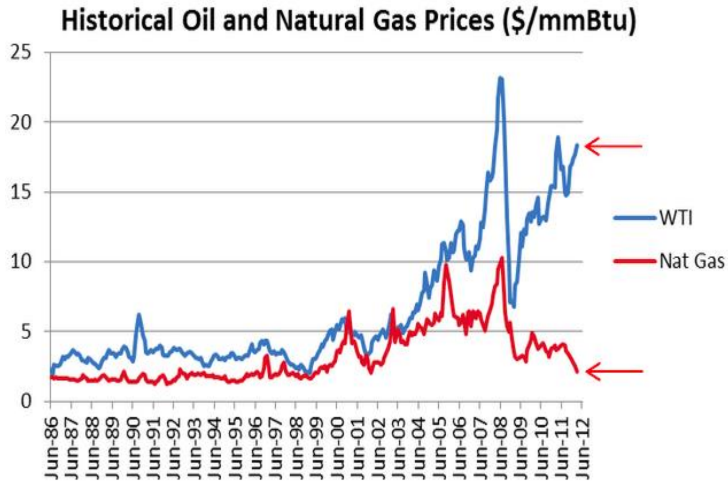

Figure 1.2: Natural gas prices in the U.S. have fluctuated but generally follow a downward trend since 2009. Oil prices (WTI), meanwhile, have risen since 2009.
Source: Avalon Energy Services

A provision of the Energy Policy Act of 2005, known by environmentalists as the 'Halliburton loophole,' exempts these natural gas extraction techniques from regulatory oversight by the US Environmental Protection Agency and disclosure of chemicals used in the hydraulic fracturing process. In 2015, challenges to this exemption were denied and the provision was upheld.

Extraction by hydraulic fracturing has raised concerns for public health and available resources of surrounding communities. Although the magnitude of environmental problems varies by proximity of extraction operations to population centers and natural resources, three areas of concern are consistent:

- Impacts on water quantity and quality,
- Changes in seismic activity, and
- Methane releases to the atmosphere.

2. Background

2.1 Legislation

The American Natural Gas Security and Consumer Protection Act was proposed by Senator Edward J. Markey (D-MA) on February 26, 2015 and is cosponsored by Senators Al Franken (D-MN), Bernie Sanders (I-VT), and Barbara Boxer (D-CA). This bill seeks to amend the Natural Gas Act of 1938 which was the country's first bill regulating natural gas. The American Natural Gas Security and Consumer Protection Act stipulates that the Secretary of the Department of Energy (DOE) should consider the concerns of American consumers and national security issues when authorizing natural gas exports.

- *Section 1:* States the name of the act as the American Natural Gas Security and Consumer Protection Act as an amendment to the Natural Gas Act of 1938.
- *Section 2:* A U.S natural gas exporter can only proceed if an authorization letter is granted from the Secretary of Energy which certifies that the exports are "consistent with public interest", defined as:

  1. The consideration of the effects of natural gas exports on household and business energy expenses.

  2. The economic effects of natural gas exports, such as the changes in energy and trade-intensive markets, along with the variances in investments and wages.

  3. The "energy security" effects of natural gas exports, with the goal of allowing the U.S to reduce reliance on foreign sources of energy.

  4. The impact of natural gas exports on the U.S geopolitical issues and national security

  5. The impact of natural gas exports on U.S greenhouse emissions.

  Furthermore, the Secretary of Energy must issue an Environmental Impact Statement in the area where the natural gas extraction takes place, in accordance with the guidelines provided under the National Environmental Policy Act of 1969 (such as identifying the adequacy of available natural resources in the area, calculating trends of natural resource extraction, reviewing local governmental programs on environmental safeguards, public meetings for community members to express concern, etc.).

- *Section 3:* Allows a clause in the Natural Gas Act of 1938 that U.S natural gas exporters can export to countries that have free-trade national agreements with the U.S. in place for natural gas, provided that the Department Of Energy still determines that exporting to these countries is consistent with the public interest in terms of the parameters in Section 2.

2.2 New Technology

The natural gas industry in the U.S. is a rapidly expanding segment of the energy sector. There are more than 6,300 natural gas producers and a combined current storage capacity of 1,989 billion cubic feet of natural gas (bcf) in the U.S. (EIA, 2015). Further growth is possible, with the U.S. Energy Information Administration (EIA) estimating that there are 2,543 trillion cubic feet (tcf) of 'drillable' natural gas reserves in the U.S., equivalent to about 90 years of supply. Major U.S. natural gas reserves are concentrated in the Gulf of Mexico and Texas, but large natural gas reserves have recently been discovered in other states such as New York, about 90 years of supply. Major U.S. natural gas reserves are concentrated in the Gulf of Mexico and Texas, but large natural gas reserves have recently been discovered in other states such as New York, Pennsylvania, North Carolina, and Arkansas (EPAc, 2013).

The United States is the world's leading producer of natural gas having produced more than 74 bcf of natural gas per day in 2014 (EIA, 2015). The expanding supply has mainly been a result of the combination of two technologies: *directional drilling* and *hydraulic fracturing.* Directional drilling allows wells to be dug into horizontal shale layers, reaching natural gas reserves that were previously unreachable. Hydraulic fracturing involves installing a cement pipe system into the shale layer and detonating a series of small explosions (EPAd, 2015). The well is then flushed with pressurized liquid consisting of water, sand, and chemicals. When this liquid is sent underground through the well, the continuous pressure forces the shale rock to open, or 'fracture.' Natural gas is released from these fractures and siphoned up through the pipe and collected aboveground. This process is visually represented in

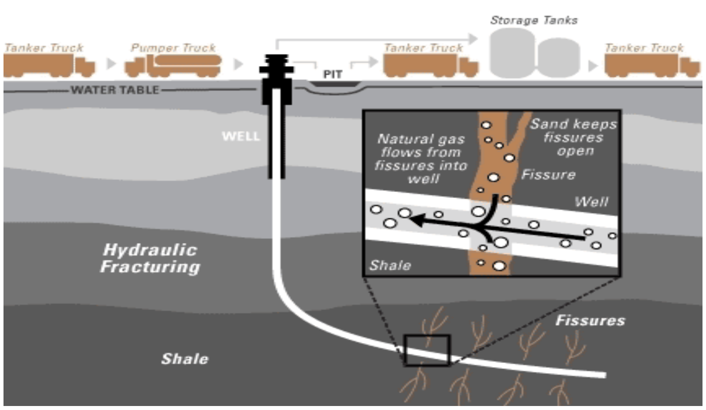

Figure 2.1: Horizontal drilling and hydraulic fracturing. *Source: H2O Distributors.*

2.3 Economic Impacts

The rapid growth of the natural gas industry has lead to historically low prices in the U.S.. Currently, NASDAQ spot prices for natural gas are around $2.80 per thousand cubic feet (tcf), with the U.S. export price being around $3.40 per tcf (EIA, 2015).

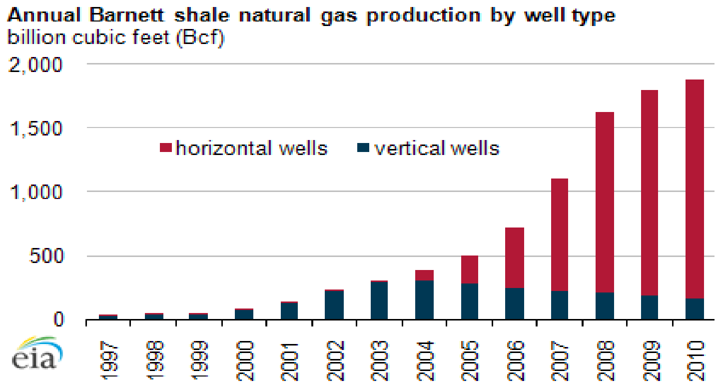

Figure 2.2: Number of vertical and horizontal wells in the Barnett Shale region (Texas). Signifying the increased use of hydraulic fracturing.
Source: U.S. Energy Information Administration.

With global prices being much higher than local prices, manufacturers and producers are eager to sell liquefied natural gas (LNG) to global markets. Figure 2.3 shows the increase of natural gas exports in the last decade. Increasing natural gas exports have been a source of contention in Congress over the past decade, with factors such as domestic price effects, energy security, and international relations all being debated at length (Cama and Marcos, 2015).

The regulation of natural gas exports is a multifaceted issue involving many international and domestic challenges. Senator Markey**,** argues that increasing exports of natural gas will lead to rising prices in the U.S., "massively exporting America's natural gas will undercut American manufacturers trying to create jobs…[raising] costs for consumers already paying high energy bills" (Markey, 2014). However, several prominent Democrats and Republicans disagree with Senator Markey. President Barack Obama's White House economic staff has reported that 65,000 jobs would be created with an increased export quota of natural gas, along with the U.S. having a strengthened "geopolitical impact" around the globe (The Energy Revolution, 2015).

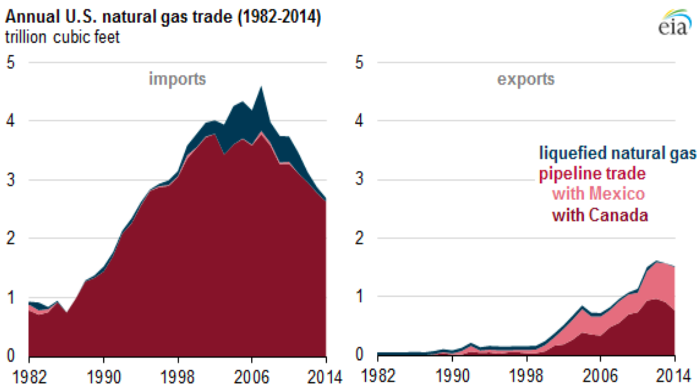

Figure 2.3: American imports of natural gas have declined rapidly, from about 4.5 tcf a year in 2006 to about 2.8 tcf a year in 2014. In the same period, exports have increased rapidly, from about 0.8 tcf a year in 2006 to 1.6 tcf a year in 2014.
Source: Energy Information Administration.

2.4 Environmental Concerns and the "Public Good"

The legislation directs the Secretary of Energy, upon two years from the bill's passage, to define the criteria of 'public good' in relation to consumer pricing, environmental impacts, and global climate change contribution. Natural gas production has been associated with several environmental issues, and balancing economic growth with the 'public good' is at the crux of the debate. The process of hydraulic fracturing is a ground-invasive procedure that could lead to water contamination, habitat degradation, and seismic disruptions (EPAd, 2015). The main focus of this report is the natural gas extraction phase—a process that can lead to severe environmental damage and profound impacts on surrounding communities.

Given the uncertainties associated with natural gas extraction, prioritizing the 'public good' in the hydraulic fracturing process is challenging. There are many environmental issues with hydraulic fracturing that are not fully understood, including:

- Exact chemicals in use during various parts of the extraction process.
- Impacts of natural gas extraction on aquifer quality and quantity.
- Health effects from exposure to hydraulic fracturing chemicals.
- Impacts of the natural gas extraction process on seismic activity.

Balancing the economics of natural gas extraction and the associated negative environmental externalities is essential to the expansion of natural gas production and exports in the U.S.

3. Environmental Issues

3.1 Water Scarcity

<u>**Water Withdrawals and Scarcity:**</u>

Water withdrawals from hydraulic fracturing operations can strain water resources (rivers, streams, lakes, and aquifers) and are a cause of concern for water-stressed surface and groundwater sources. The average water use per well is 4.4 million gallons (Pennsylvania, 2015). Hydraulic fracturing creates *produced water*. This produced water has chemical constituents from hydraulic fracturing fluid and naturally occurring sources and must be permanently disposed of after use, thus removing billions of gallons from local water supplies annually (Environment America, 2015).

Hydraulic fracturing operations in the U.S. have used over 250 billion gallons of water since 2005 (Figure 1) and nearly half of all extraction sites are located in areas with high or extremely high water stress (Freyman and Salmon, 2013). The highest water withdrawals occur in the Barnett Shale formation in Texas, consuming as much as 9% of the annual water use of Dallas, Texas (80,000 mgal) (Nicot and Scanlon, 2012).

Excessive water withdrawals can also lead to a reduction in water quality. A study by the U.S. Army Corp of Engineers in 2011 concluded that the Monongahela River basin of Pennsylvania and West Virginia had "unregulated" quantities of water withdrawn for hydraulic fracturing, concentrating contaminants and causing the water to be potentially unsafe as a drinking water source. Cleaning these polluted sites is not an easy process—the Corps' ability to clean the river basin are limited further by water diversions for hydraulic fracturing from Corps-maintained clean water reservoirs where polluted water is cleaned during low-flow periods.

State	Total Water Used Since 2005 (Million Gallons)
Arkansas	26,000
Colorado	26,000
Kansas	670
Louisiana	12,000
Mississippi	64
Montana	450
New Mexico	1,300
North Dakota	12,000
Ohio	1,400
Oklahoma	10,000
Pennsylvania	30,000
Tennessee	130
Texas	110,000
Utah	590
Virginia	15
West Virginia	17,000
Wyoming	1,200
Total	**250,000**

Figure 3.1.1: Total Water Use by State from Natural Gas Production since 2005.

Source: Environment America, 2013

Wastewater Handling

The hydraulic fracturing process produces large quantities of wastewater, and much of this wastewater ends up in disposal wells, concrete pits, and storage containers. In 2012, over 280 million gallons of wastewater was produced from hydraulic fracturing in the U.S. (Figure 3.2). Many states do not have an estimate of wastewater production due to a lack of reporting laws for wastewater from extraction operations (U.S. Army Corp of Engineers, 2015).

There are several methods for the disposal of wastewater. In some cases, the wastewater produced is re-injected into depleted wells or held in concrete pits (holding ponds) near the extraction site to be decontaminated later. Wastewater in these pits can potentially leak into the surrounding soil and groundwater due to infrastructure failure (Environment America, 2015). Sometimes, wastewater is transported to other states when the volume exceeds local capacity. For example, in 2011 more than 100 million gallons of wastewater was trucked from extraction sites in Pennsylvania to Ohio for storage in injection wells (Schmidt, 2013). Hydraulic fracturing is exempted from the Resource Conservation Recovery Act (RCRA), which is the national framework for regulating toxic waste. Absent of wastewater regulations, increased natural gas production could increase the risks of groundwater contamination (Environment America, 2015).

State	Wastewater Produced (Million Gallons)
Arkansas	800
Colorado	2,200
Kansas	No Estimate
Louisiana	No Estimate
Mississippi	10
Montana	360
New Mexico	3,000
North Dakota	12,000
Ohio	30
Oklahoma	No Estimate
Pennsylvania	1,200
Tennessee	No Estimate
Texas	260,000
Utah	800
Virginia	No Estimate
West Virginia	No Estimate

Figure 3.1.2: Wastewater Produced by State from Natural Gas Production.

Source: (Environment America, 2013)

Wastewater contains pollutants from hydraulic fracturing fluids and naturally occurring processes underground. Local communities can be affected by hydraulic fracturing procedures. For instance, process failures in regions such as the Marcellus Shale, where natural groundwater migration occurs, can cause contamination with fracturing fluid constituents such as benzene or toluene by cross-contamination within aquifers (Warner, 2012).

3.2 Water Contamination

The increase in hydraulic fracturing projects has impacted both surface and groundwater sources. Water contamination from hydraulic fracturing happens primarily in two ways:

- Leakage and spilling of hydraulic fracturing fluids on- and off-site as a result of failed containment structures (EPAa, 2015)
- Escape of fracturing fluids and methane via leaky gas-well casings, formation fractures, and natural conductive pathways (Osborn et al., 2011).

Waste pits, for example, in New Mexico have seen contaminated groundwater events as many as 421 times within the last decade (Environment America, 2013).

Another example groundwater contamination by hydraulic fracturing wastewater discharge occurred in the Monongahela River, which starts in Pennsylvania and ends in West Virginia. An advisory was issued to as many as 350,000 residents along the Monongahela River in 2011 due to the presence of trihalomethanes from wastewater (Environment America, 2013). Trihalomethanes are harmful to humans as they may cause reproductive health issues as well as cancer (Madabhushi, 1999).

Chemical Mix

Fracking fluids are made up of water, sand proppants, and other proprietary chemical mixes. The chemical mixes include: methanol, glutaraldehyde, ethylene glycol, diesel, naphthalene, xylene, hydrochloric acid, toluene, and ethylbenzene, many of which are volatile organic compounds, known human carcinogens, and persistent organic pollutants (Environment America, 2013).

FracFocus, a voluntary chemical disclosure registry, indicated that one-third of all hydraulic fracturing projects use at least one carcinogenic chemical with the potential to enter drinking water supplies from a well, the immediate area around the well (well pad), or during the wastewater disposal process as transportation vehicles leave the drilling site (Environment America, 2013).

Of the 1,076 chemicals used for hydraulic fracturing, 453 strongly associate with soils and organic materials suggesting a potential for these chemicals to persist in the environment indefinitely (EPAa, 2015). The physical and chemical properties are only known these 453 chemicals individually. How they interact with one another and what the accumulated health risks as a result of various combinations is unknown (EPAa, 2015). The effects on public health may vary as many of these recognized chemicals are known to have acute and/or chronic effects.

Chemical Name	Chemical Purpose	Health Effects
Hydrochloric Acid	Dissolves minerals and initiate cracks in the rock - Acid	Acute: Corrosive to the eyes and skin Chronic: Causes gastritis, dermatitis
Methanol	Product stabilizer and/or winterizing agent - Corrosion Inhibitor	Acute: Causes mild dermatitis, blurred vision Chronic: Causes conjunctivitis, blindness, insomnia
Boric Acid	Maintains fluid viscosity as temperature increases - Crosslinker	Acute: Causes skin irritation, low blood pressure Chronic: Causes convulsions and anemia
Naphthalene	Carrier fluid for the active surfactant ingredients - Surfactant	Acute: Damage to liver and in infants, neurological damage Chronic: Causes lung and nasal inflammation, cataracts

Table 3.2.1: Examples of Chemicals Used in hydraulic fracturing Fluids and Their Health Effects
Sources: FracFocus, 2015; EPA, 2000; National Pesticide Information Center, 2013;

Certain chemicals are used more often in the hydraulic fracturing process than others due to specific chemical purposes (Table 3.2.1). When pressure from hydraulic fracturing is decreased, fracturing fluid flows back to the surface. The composition of the "flow-back" fluid changes as a function of the amount of time in contact with the formation as well as location and when minerals and dissolved organic compounds from the formation are combined, a brine, or salinized, solution is created (Gregory, 2011) . Flow-back water is collected at the surface for disposal, treatment, or reuse. Most flow-back water from oil and gas production is disposed of through deep underground reinjection (Gregory, 2011). The flow-back water can contaminate groundwater and management of these flow-back fluid poses concerns due to the chemical composition of flow-back fluid and possible human health and environmental impacts. This makes it necessary to construct specific treatment plants for hydraulic fracturing waste (Gregory, 2011).

Methane Migration

Three major pathways for methane to migrate into water aquifers exist:

- Leaky gas-well casings (Osborn et al., 2011).
- New and existing fractures, above depleted shale formations (Osborn et al., 2011).
- Natural conductive pathways that allow fluids and methane to migrate into shallow aquifers (Warner, 2011).

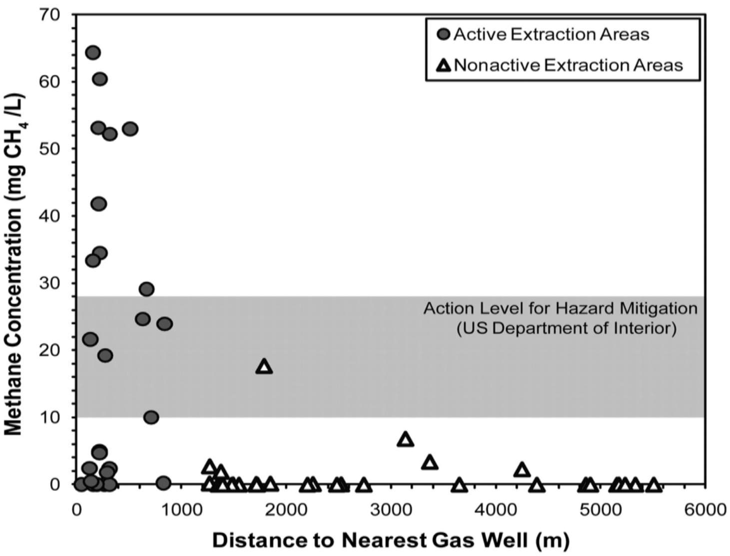

Figure 3.2.1: Methane concentration in water by distance to nearest gas well.
Source: Osborn et al., 2011

As shown in Figure 3.2.1, a correlation between proximity of gas wells and methane concentration in water exists. The circles on the graph represent active extraction areas while the triangles represent non-active extraction areas. This figure illustrates that as the distance to the nearest gas well decreases, the concentration of methane in the water is higher, which corresponds with active drilling sites (Osborn et al., 2011).

3.3 Seismic activity

Recent research shows the frequency of seismic activity has a positive correlation with natural gas extraction operations such as the injection of fracturing fluid and reinjection of wastewater. When fracturing fluids are injected into the shale level, extremely high-pressure fluids fracture the geologic formation. According to Dr. Katie Keranen from Cornell University, wastewater reinjection can cause many small earthquakes (Richter Scale 0.5 to 2.0).

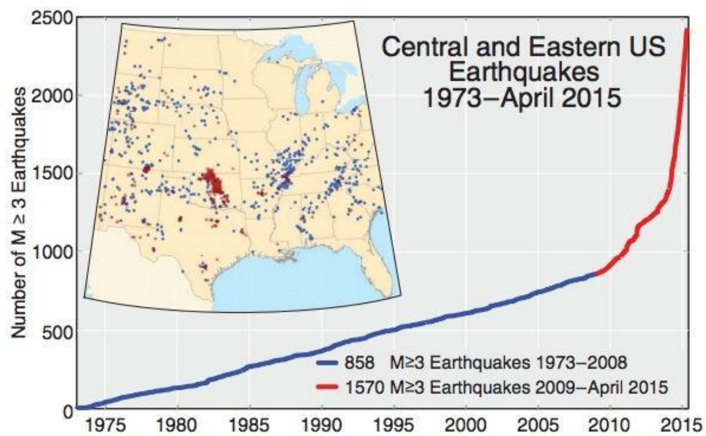

Figure 3.3.1: Count of ≥ 3.0 M earthquakes in the central and eastern U.S. from 1973 to April 2015.

Source: Rubinstein and Mahani, 2015

The figure from the USGS shows that in the central U.S., the number of earthquakes has increased dramatically in the past six years. The number of earthquakes increased from an average of 24 earthquakes with a magnitude of 3 M or greater per year from 1973 to 2008, to an average of 193 earthquakes with Richter Scale 3 or greater per year from 2009 to 2014 (Rubinstein and Mahani, 2015). In 2014 alone, there were 688 earthquakes with Richter Scale of 3 or greater (Rubinstein and Mahani, 2015). Damaging earthquakes include the 2011 Richter Scale 5.6 in Prague, Oklahoma; the 2011 Richter Scale 5.3 in Trinidad, Colorado; and the 2011 Richter Scale 4.7 in Guy-Greenbrier, Arkansas (Rubinstein and Mahani, 2015).

The increasing seismic activities are limited to a few states, such as Oklahoma, which appear to be induced by wastewater reinjection (Rubinstein and Mahani, 2015). According to US Census data from July 2014, the earthquake locations have the following populations: Prague, Oklahoma - 2,428; Trinidad, Colorado - 8,465; and Guy-Greenbrier - 5,822.

When fracturing fluids and wastewater are injected into a reservoir, the pressure within the reservoir rises. When the pressure reaches geological faults, the increased pressure can push the fault, which causes an earthquake. The fluid pressure, size of the well, and duration of the injection all influence the strength and probability of an earthquake (Rubinstein and Mahani, 2015). Earthquakes at a greater distance and over a longer time span are more likely to be induced by wastewater injection than by hydraulic fracturing (Rubinstein and Mahani, 2015).

3.4 Methane Emission

The natural gas production chain (extraction, storage, and transportation) provides many opportunities for methane leakage into the atmosphere (see Figure 2.1). For producers, decisions regarding the control of methane leakage are based on economics. Domestic prices of natural gas are so low in comparison to abatement technologies that methane capture is not cost-effective (Ogburn, 2014). Without regulation and enforcement to control methane leakage, companies will not cap leaks until it is cost-effective. The Environmental Defense Fund projects the initial capital outlay at $2.2B (Economic Analysis, ICF International). Also important to note is that leaks occur locally, but have implications that are potentially global. Consequently, understanding the long term impacts of methane leakages in the atmosphere and the associated effects on the public interest, is critical.

In order to understand methane's atmospheric impact, it is important to understand the greenhouse gas effect and how anthropogenic methane leaks contribute to the greenhouse effect (see Appendix II).

The natural gas production process leaks methane directly into the atmosphere. Methane (CH_4) is the second most prevalent greenhouse gas after carbon dioxide (CO_2), representing 10% of annual emissions (EPAa, 2015). The warming effect of methane is 25 times greater than that of carbon dioxide over a 100 year period, making it the most potent greenhouse gas (EPAa, 2015). Consequently, it is in the public interest to take reasonable measures to address methane leaks in the natural gas production process (EPAa, 2015).

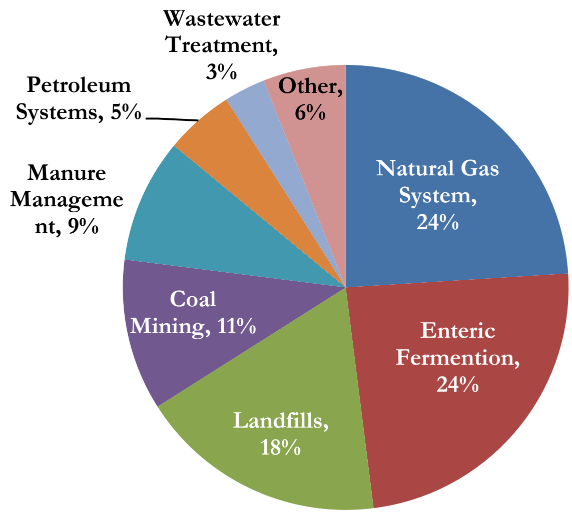

Figure 3.4.3 - Sources of Greenhouse Gases, 2013. *Source: c2es.org, from the EPA.*

Figure 3.4.3 above shows that Natural Gas accounts for 24% of the methane emissions according to the EPA. Methane is the primary gas leaked into the atmosphere from hydraulic fracturing (EPAa, 2015).

A report from Environmental Defense Fund shows that the U.S. leaks 65 billion cubic feet of natural gas into the air annually (Rong, 2015). This leakage is equal to the pollution released by 5.6 million cars (Hauter, 2015). Senior Research Fellow Hugh MacMillan from the Food and Water Watch estimates that the leakage from the gas extraction process is about 2.2%. Including transportation, the percentage of leakage in the process rises to 3% (Hauter, 2015).

Methane leakage not only impacts the air, it also impacts groundwater.

The technology used in hydraulic fracturing may not always lead to contaminated water, but there are instances in which drinking water has been contaminated with methane and other chemicals. A study was performed by scientists from Duke University showing that 82% of wells near natural gas extraction sites contain some methane (Drouin, 2014). The report comes as the Bureau of Land Management (BLM) has provided data showing how this could happen.

The natural gas losses each year by oil and gas companies operating on federal and tribal lands through leaks and intentional venting and flaring is valued at more than $360 million at current market prices (see Figures 3.4.4 and 3.4.5). This is enough natural gas to meet the heating and cooking needs of 1.6 million homes annually (Bradbury, 2013). Companies are usually not required to pay royalties when natural gas that is extracted from federal lands has been lost. Natural gas losses on federal lands in 2013 had a value of $32 million in taxpayer royalties. The report estimates that companies can reduce oil and gas methane emissions on federal and tribal lands by nearly 40%, using available methane mitigation techniques (Bradbury, 2013).

4. Proposed Solutions

4.1 Policy Solutions

One of the major challenges regarding the environmental impacts from hydraulic fracturing are the many uncertainties. For example, we do not know:

- Which chemicals are used at individual sites
- Which chemical combinations are used at each point in the extraction process
- How hydraulic fracturing affects aquifer size and water quality
- Wastewater injection volume and timing associated with seismic activity
- How much methane is released to the atmosphere

Our recommendation is to approach each of these uncertainties using the "precautionary principle," meaning that prior to extraction projects the potential risks should be thoroughly studied and, when faced with uncertainties, to err on the side of caution (UN, 2000). From a regulatory perspective, there are several actions that can be taken to mitigate the potential environmental impacts of hydraulic fracturing. Primarily, requiring chemical disclosure for each extraction site combined with a robust surface and groundwater monitoring program that establishes baseline chemical levels before projects begin. Better monitoring of fugitive methane emissions and requirements for emissions reduction should also be considered. Additionally, a ban on wastewater reinjection would be an effective regulatory solution until wastewater injection and seismic activity are better understood.

Technical solutions to address the other issues mentioned above, will be addressed later in this report.

<u>4.1.1 Water Contamination Solutions</u>

There is no federal law requiring companies to identify the chemicals used in hydraulic fracturing prior to drilling. As of today, some states have already introduced chemical disclosure requirements. Only seven states (Alabama, Arkansas, Michigan, Montana, Ohio, Texas, and Wyoming) mandate the chemical identification of all additives used in hydraulic fracturing as of July 2012 (see Figure 4.1.1) (McFeeley, 2012). In addition to these seven states, some states have chemical disclosure requirements, but these are limited only to hazardous substances defined by the Occupational Safety and Health Administration (OSHA). Furthermore, some states do not have chemical disclosure requirements at all (McFeeley, 2012).

Due to the lack of federal requirements for chemical disclosure, it is difficult to identify chemical contaminants and analyze their transport in the environment and impacts on human health in surrounding communities. We recommend that there should be uniform federal regulation requiring all natural gas production companies to disclose chemicals used prior to natural gas extraction.

We further recommend that carcinogenic chemicals be removed from fracturing fluid. In addition, more stringent monitoring requirements should be required at extraction operations using EPA Maximum Contaminant Levels (MCL) to ensure levels in ground and surface water do not exceed levels that are harmful to human health.

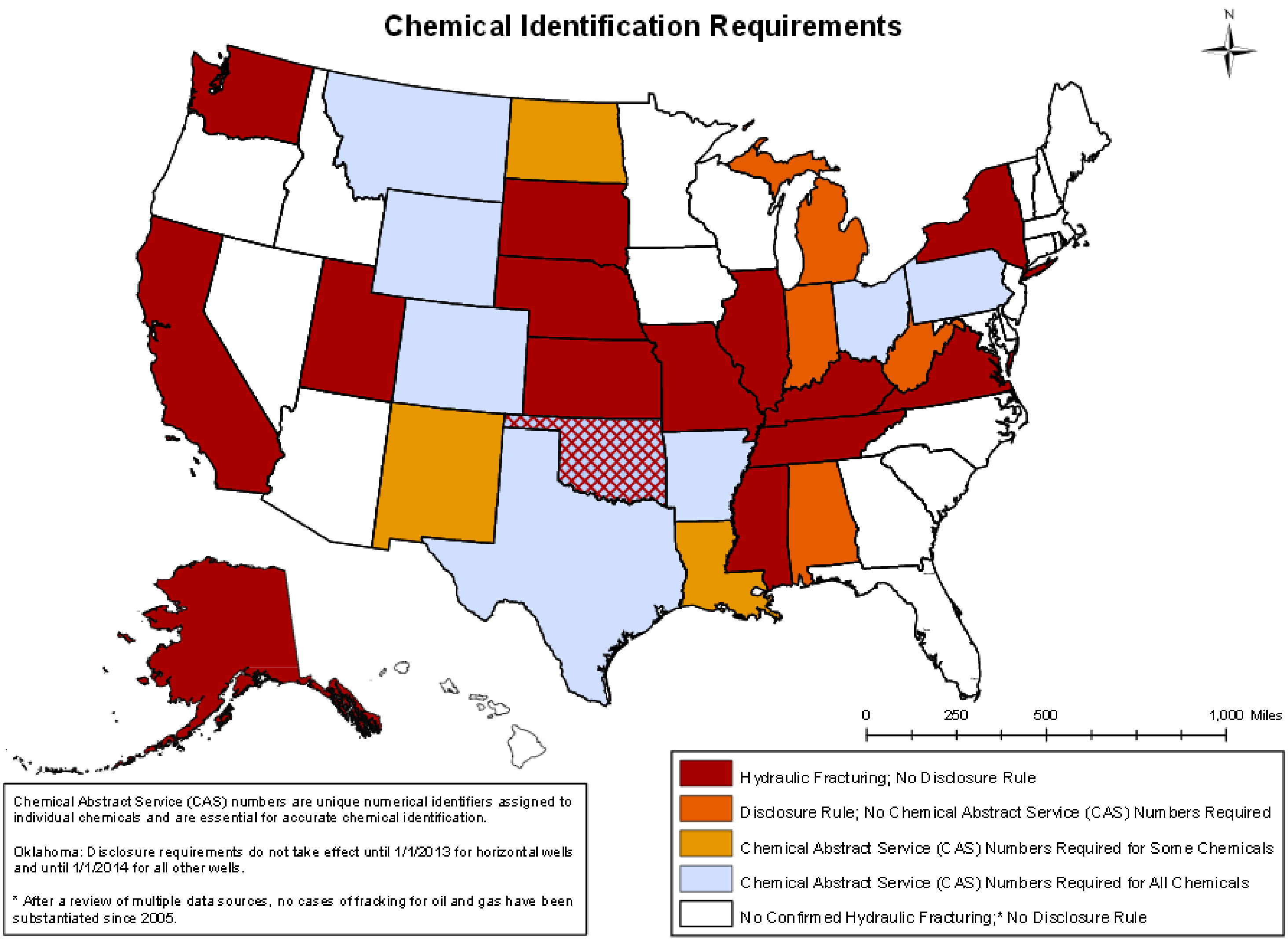

Figure 4.1.1: Chemical Identification Requirements
Source: Natural Resource Defense Council

We further recommend that carcinogenic chemicals be removed from hydraulic fracturing fluid. In addition, more stringent monitoring requirements should be required at extraction operations using EPA Maximum Contaminant Levels (MCL) to ensure levels in ground and surface water do not exceed levels that are harmful to human health.

4.1.2 Seismic Activity Solutions

With regards to seismic activity, our primary policy solution is to ban reinjection of wastewater into wells. We also recommend a Traffic Light Monitoring System for extraction using hydraulic fracturing.

Under this system, a threshold magnitude of Richter Scale 0.5 should be viewed as a warning sign. Hydraulic fracturing should be discontinued if magnitudes of Richter Scale 3.0 occur, as this could begin to cause property damage (Green et al., 2012). In "Traffic Light" terms, a green light means that hydraulic fracturing can go as planned; yellow means that hydraulic fracturing should proceed with caution at reduced rates; and red means that hydraulic fracturing should be suspended immediately (Department of Energy & Climate Change, 2013). If the solution is successful, a reduction in the frequency and magnitude of earthquakes will occur. Furthermore, these solutions will only be given serious consideration if an incentive for gas companies to monitor seismic activity exists.

4.2 Technical Solutions

The extraction phase of hydraulic fracturing can impact the: hydrosphere, lithosphere, and atmosphere. These impacts, including air and water contamination, water scarcity, and seismic activity, will mostly affect communities near extraction sites. This report focuses on the following three technical solutions that can help to mitigate environmental impacts: water-free hydraulic fracturing, on-site wastewater treatment, and emissions abatement technologies. The benefits of these solutions vary from site to site and are dependent on individual site conditions. Although these solutions are neither comprehensive nor perfect, these measures will likely help to mitigate the environmental problems caused by hydraulic fracturing.

4.2.1 Water-free Hydraulic Fracturing

According to the EPA, hydraulic fracturing in the U.S. uses on average 44 billion gallons of water (EPAa, 2015). The national median volume of approximately 1.5 million gallons of water per hydraulically fractured well adds further stress on water resources in water scarce areas, along with the possibility of surface and groundwater contamination (EPAa, 2015). The solution of water-free hydraulic fracturing is a possible solution to address water withdrawals as well as water contamination, as it uses little water and far fewer chemicals.

Water-Free hydraulic fracturing is a relatively new method of natural gas extraction. The process was first developed by Chevron in the 1990s. Chevron licensed the process to GasFrac in 2006, a Canadian company based in Alberta (Harrington, 2012). GasFrac uses one-eighth of the liquid required for conventional hydraulic fracturing, pumping at a slower rate, it limits the need to drain contaminated wastewater and lessens exposure to toxins (Kiger, 2014). The water-free process uses liquefied petroleum gas or LPG (C_3H_8), instead of water, in a closed-loop system that uses specialized tanks, pumps, blenders, and other equipment. The process uses a thick propane gel that is a mix of light hydrocarbons including propane, butane, and pentane. Unlike water, the gel returns to the surface without drilling chemicals, ancient seabed salts, and radioactive elements. This method allows more gas to flow from wells than the water-based process (Brino, 2011). Another interesting feature is that the gel changes phase during the process, and flows back as a vapor, along with the natural gas production stream, which minimizes clean up requirements. Although we believe that the chemicals used in this process are not dangerous to human health, not all chemicals used in the process have been disclosed and further information is required (Thomas, 2011). This technique has been used about 2,500 times at 700 wells in Canada and the U.S. including: Texas, Pennsylvania, Colorado, Oklahoma, and New Mexico (Brino, 2011). However, from an economic perspective, water-free costs 25% more than conventional hydraulic fracturing, in part because of the high cost of the propane (Kiger, 2014).

Picture 4.2.1: GasFrac Energy Services, Inc. Water-free hydraulic fracturing.
Source: GasFrac Energy Sources Inc.

In order to measure the success of water-free hydraulic fracturing, we can use either historical average of groundwater level or water use per well as an indicator of success. A decrease in water-use per well would indicate success.

Shale Formation	Water per Well (Million Gallons per Year)	Natural Gas Production per Well (Million Cubic Feet per Year)
Bakken (North Dakota, Montana)	1.5	100,010
Eagle Ford (Texas)	4.3	413,180
Marcellus (New York, Pennsylvania, Ohio)	4.5	1,554,535

Figure 4.2.1: Average water use per well by shale formation in water-based hydraulic fracturing.
Source : USGS, Web. 26 July 2015; EIA, "Drilling Productivity Report," accessed 26 July 2015.

4.2.2 On-site Wastewater Treatment

Chemicals used in hydraulic fracturing are difficult to treat at municipal water treatment plants, as they are not equipped to treat this water.

The shared responsibility for the treatment and disposal of wastewater falls on the states and the EPA under the National Pollutant Discharge Elimination System. Natural contaminants such as barium, calcium, sodium, and chloride can be dissolved through natural water treatment stages and processes (EPA, 2013b); however, it is incredibly difficult to treat "produced water" from hydraulic fracturing because we are unsure of what chemicals are present. In the process of wastewater treatment, most chemicals may be removed through charge neutralization, dissolving chemicals by adding other chemicals. This process then continues with the physical separation process where volumes of water are separated based on density at various depths. Then, metals are physically removed through sedimentation. Onsite pretreatment of wastewater plays a critical role as the process can reduce toxicity and the wastewater can then be transferred to treatment facilities by setting treatment quality specifications onsite (Beckman et al.).

A growing onsite water treatment process involves using water with fewer additives known as "Frac Fluid" and an onsite system that can treat the wastewater (Gruber, 2013). This process allows for the use of fewer man-made chemicals replaced by natural chemicals that can be treated onsite with less time and effort (Gruber, 2013).

4.2.3 Emissions Abatement Technologies

According to a report in *Science* magazine (Brandt, 2014), from an overall perspective, the benefits of buses switching to methane from diesel is outweighed by the methane leakage in the process. However, natural gas usage for generating electricity still has a lower greenhouse gas impact than that of coal, according to the same study (Brandt, 2014).

Our proposed solution is to use existing technologies to find and plug methane leaks. One technology for detecting leaks is to use infrared cameras (see Figure 4.2.3.1). According to the EPA, stopping the leaks requires tightening pipes, changing plunger valve systems, and using "green completion" techniques.

Figure 4.2.3.1 - Methane leakage detection using infrared. The picture on the left shows methane storage tanks taken with a regular camera. The photograph on the right is an infrared (IR) image. The "smoke plumes" are the methane leaks.
Source: Clean Air Task Force

Green completion is technique that shows promise for limiting methane leakage. In the past, methane at the wellhead was either allowed to leak into the atmosphere, or was flared off. This technique involves capturing the gas instead of allowing it to escape or to be flared. Green completion is a new requirement by the EPA, effective January 1, 2015.

This technique not only limits emissions to the atmosphere, but preliminary evidence suggests it is economically beneficial as well (Bunzey, 2012).

These mitigation technologies are available and can reduce the amount of anthropogenic methane that reaches the atmosphere by 13% in 2015 and up to 25% in 2035 with proposed EPA regulations (Bradbury, 2013). The EPA is proposing tracking the amount of methane that leaks from the natural gas production process, but the data is not available at this time.

On January 2015, the White House announced a goal to reduce the total methane emissions from oil and natural gas extraction by 40% to 45% below 2012 levels by 2025 (Podesta, 2015). To achieve this goal, the EPA will work with industry, states and others to develop standards. At the same time, the Department of Energy will invest in supporting technological improvements and the Department of the Interior will ensure that standards are updated for drilling on public lands. Voluntary efforts are also expected by the natural gas industry (Podesta, 2015).

5. Conclusion

The recent expansion of natural gas production in the United States has positioned the U.S. as the number one producer of natural gas in the world. The pricing disparity between lower domestic natural gas market prices and higher prices on the global market incentivizes natural gas exports from U.S. producers. Increased exports open up previously unrealized economic opportunities for natural gas production companies, but at what cost?

Increasing natural gas exports will likely raise U.S. consumer costs and lessen the country's ability to become independent of foreign energy sources. New techniques in natural gas extraction (i.e. hydraulic fracturing) will also have negative environmental impacts on hydrologic, lithospheric, and atmospheric earth systems. This report outlined the environmental issues involved in natural gas extraction including: surface and groundwater contamination, extensive withdrawals from local water sources, seismic disturbances and methane emissions. The environmental issues will adversely impact the health and environments of communities surrounding natural gas extraction sites, as well as contribute to global climate change.

Senator Markey's legislation (S. 585) would require the Secretary of Energy to define public good in relation to natural gas production (most importantly, the extraction phase) and balance the economic benefits with the environmental impacts borne by local and global communities. The Secretary will then need to consider this balance before authorizing natural gas exports.

This paper evaluated existing scientific evidence and proposed potential solutions the Secretary could require, and natural gas production companies could adapt, to lessen impacts of natural gas extraction on local communities and the global climate system. The potential solutions are valuable recommendations for addressing possible negative impacts on Americans that result from the economic benefits of increased U.S. natural gas exports.

6. Appendix

I. Acronyms List

Bcf: Billion Cubic Feet

BLM: Bureau of Land Management

CAA: Clean Air Act

CH_4: Methane

CO_2: Carbon Dioxide

CWA: Clean Water Act

DOE: Department of Energy

DOI: Department of the Interior

EIA: United States Energy Information Administration

EPA: United States Environmental Protection Agency

GHG: Greenhouse Gas

H_2O: Water

IR: Infrared Radiation

LNG: Liquefied Natural Gas

LPG: Liquefied Petroleum Gas

MCL: Maximum Contaminant Level

OSHA: Occupational Safety and Health Administration

RCRA: Resource Conservation and Recovery Act of 1976

S. 585: The American Natural Gas Security and Consumer Protection Act

SDWA: Safe Drinking Water Act

Tcf: Trillion Cubic Feet

U.S.: United States

UN: United Nations

6. Appendix

II. Greenhouse Effect and Global Climate Change

The natural gas production chain (extraction, storage, transportation etc.) provides many opportunities for methane leakage. Understanding the long term impacts of methane leakages in the atmosphere, and the associated effects on the public interest, is critical. In order to understand methane's atmospheric impact, it is important to understand the Greenhouse Effect. According to the Environmental Protection Agency, the Earth's Greenhouse Effect works as follows:

- When sunlight reaches Earth's surface, it can either be reflected back into space or absorbed by Earth.
- Once absorbed, the planet releases some of the energy back into the atmosphere as heat (also called infrared radiation).
- Greenhouse gases (GHGs) like water vapor (H_2O), carbon dioxide (CO_2), and methane (CH_4) absorb energy, slowing or preventing the loss of heat to space.
- In this way, GHGs act like a blanket, making Earth warmer than it would otherwise be.

The earth's temperature has risen close to 2 degrees centigrade in the past hundred years. According to the National Snow and Ice Data Center, in September, 2016, artic ice reached 1.32 million square miles, 49% lower than when records started in 1979. According to the National Oceanic and Atmospheric Administration, sea level rise has been about 10 inches over the course of the past hundred years on a global average, with much bigger local variations.

Methane (CH_4) is the second most prevalent greenhouse gas after carbon dioxide (CO_2), representing 10% of annual emissions. The warming effect of methane is 25 times greater than that of carbon dioxide on a comparable scale, making it the most potent greenhouse gas. Consequently, it is in the public interest to take reasonable measures to address methane leaks in the natural gas production process.

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