Natural Gas as a Bridge Fuel:
A Case Study of Natural Gas & Coal in Pennsylvania

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Executive Summary

Hydraulic fracturing has become one of the most recent technological advances, and it has been labeled as a possible method of extracting natural gas, the "bridge fuel" for coal, in the future. The process of hydraulic fracturing is to capture natural gas that is found in shale rock. The primary way of recovering such natural gases from the shale rock is through the use of a water mixture that is pumped into the places where natural gas is reserved. Throughout recent years there has been many controversies related to the topic of hydraulic fracturing and its effects on the environment. Many findings have supported the use of hydraulic fracturing, while there are still others who are skeptical of the process as a whole. Because of its history with hydraulic fracturing, the state of Pennsylvania acts as a case study to see the possible effects this process has in climate change on a regional scale. Through the exploration of different factors, such as water usage, greenhouse emissions, policy, and business, the paper will establish effects and recommendations of hydraulic fracturing for the Pennsylvania Department of Environmental Protection.

Water usage from hydraulic fracturing is a major concern for not only the department, but for the citizens of the areas that are affected by hydraulic fracturing. The usage of water is a vital component of hydraulic fracturing; however, there are two major concerns including, source and disposal. With its abundant amounts of water sources from the Great Lakes and groundwater sources, Pennsylvania is an ideal location for hydraulic fracturing. The findings of this study indicate that the amount of water used for hydraulic fracturing is much less than coal in terms of generating electricity. Further analysis illustrates the hazards, such as trace amounts of radiation that are associated with disposal of the fracking brine as it surfaces back to the ground.

The emissions of hydraulic fracturing can contribute to the amount of methane (CH_4) and carbon dioxide (CO_2) that is given through the burning of fossil fuels and natural gas. The main objective is to establish whether these emissions have a significant impact on greenhouse gas emissions overall, and to answer the question of whether fracking will lead to decreases or increases in these greenhouse gases compared to other forms of energy production. Although the scope of this study is primarily in Pennsylvania, the findings will show how these emissions are affecting the regional climate, and how the same amount of emissions will affects other areas that are different from the case study's location.

Further analysis for hydraulic fracturing is made with respect to policy and business implications within the area. For many years, Pennsylvania has been one of the most technologically advanced states in the U.S. to deploy hydraulic fracturing as a way for energy production. Many policies have been enacted to ensure the safety and welfare of citizens in the area, and some businesses have started taking action, converting their coal-powered plants to natural gas-powered. Findings from this research show that the operating cost of coal plants with expensive pollution control retrofits are significantly higher in most cases to the operating costs of natural gas power plants.

Therefore, hydraulic fracturing shows potential for becoming a possible environmentally sound way of extracting natural gas. The water usage proves to be minimal compared to the amount of water needed for coal energy production. Although hydraulic fracturing does contribute to greater amounts of CH_4 emissions, there are efforts of lessening the amount of CH_4 through greener technology. The use of policy and business brings a societal aspect of hydraulic fracturing because of the efforts that have been made to lessen the ecological effects of the process. With these factors in mind, this paper provides a detailed perspective of how hydraulic fracturing is affecting the way we perceive climate change.

Introduction

With the recent technological advances in hydraulic fracturing, the U.S. has become the world's largest producer of oil and is projected to become an exporter of natural gas. Pennsylvania has been known as one of the leaders in fracking technology, along with having a long history of producing coal. We investigate hydraulic fracturing in this state by looking at water use, emissions, policy, and business implications. Based on this analysis, we have developed recommendations to address concerns. This report is directed to the Pennsylvania Department of Environmental Protection.

Water

What is often neglected or forgotten during the generation of energy is the use of water as a tool in production- from cooling nuclear plants to cleaning and processing coal to our subject of interest, fluid in hydraulic fracturing. As one of the pioneering states in oil production, Pennsylvania continues to be on the leading edge of hydraulic fracturing. When first examining the technology, it becomes clear that fracking in Pennsylvania uses a significant amount of water in its processes. While there are many risks and concerns with using this water, one feature of Pennsylvania that makes it prime for fracking is the abundance of perceived water resources. There are a variety of concerns over water for fracking use, particularly Potential Source Reductions and Disposal. While states in the desert southwest currently battle over access to water, Pennsylvania doesn't lack the resources to create the fracking brine solution. This does not calm dissenters who disagree with the impact of water use. In addition, the disposal method once the solution has been used is a hotly contested topic. With fracking fluid retrieval bringing up radioactive isotopes, few processing plants are able to handle the cleaning demand. These concerns all bring real problems to the table, but have differing levels of validity in application.

The process of hydraulic fracturing according to the American Petroleum Institute typically uses a solution that is composed of 95+% water and sand. However, in many regions that have perpetual water shortages new varieties of fluids including butane and gelled propane are being tested. This can be seen with the recent deployment of butane as a fracking fluid in parts of Texas[1]. Butane, however, has not caught on as a fracking fluid in the State of Pennsylvania. This is especially surprising since fracking in Pennsylvania utilizes between 4 and 8 thousand million gallons of water annually across the state[2]. Of this water, approximately 65% comes directly from rivers, lakes, and streams, with the rest being gathered from municipal water systems.[2] When analyzed for precipitation, it is estimated that over a typical year, it only takes 17 days of rainfall in Pennsylvania to produce all the water needed for fracking annually. Because of this relatively small percentage of water being used compared to available resources, the impact of fracking on available water resources is clearly much lower than in some southern states where the rainfall days needed remain significantly higher. Drawing of water resources from communal sources does not pose a risk to water security for residents in Pennsylvania in the near term. However, looking toward long term security, based on USGCRP projections, even with projected climate changes, Pennsylvania is expected to have 10-20% more precipitation on average as seen in the plot below[5].

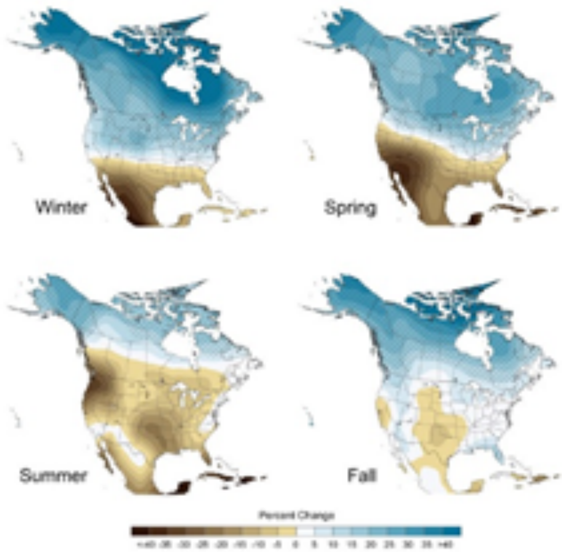

Figure 1: EPA- Precipitation projections from USGCRP 2009

While the availability of water resources in Pennsylvania might not be a major concern in the future, the resulting effluent from fracking is another consideration. Following the process of hydraulic fracturing, approximately 80-90% of fluid is returned to the surface. Since the introduction of hydraulic fracturing, there have been a number of stories of people finding contaminated water (groundwater) near fracking sites. One such instance in Pennsylvania brought about much media attention to a 'flammable water faucet'. With over 1 million views and almost 1,500 comments, this video has sparked controversy around cross-contamination between fracking wells and groundwater sources. Industry experts claim that the natural gas concentrations in these wells were naturally there, but that hasn't put to rest concerns about contamination in some PA wells of over six times those nearby[3]. A Penn State analysis determined that in New York State, approximately 53% of wells contained measurable levels of natural gas[4]. While natural gas may be found normally in some water resources, there have only been conclusive cases of leaking of fracking fluid into water. In 2011 the EPA conclusively determined that in at least one well cross-contamination had occurred[5]. This confirmation that fracking can cause water contamination, while not confirming the concern of methane/gas contaminations, brings up the issue of contamination of fracking brine.

This contamination is a major concern, as Pennsylvania has had a number of occurrences where fracking fluid has returned to the surface with significant measurable quantities of radiation. There is naturally occurring radiation, however it needs to be treated before it is safe to dump back into ecosystems. Given the radical increase in the amount of fracking being performed, there simply is not the capacity in waste water treatment facilities to tackle the volume of water needing to be processed.[6] With a 570% increase since 2004 in waste from fracking going into the municipal wastewater treatment system, there has been significant stress to adequately process the brine. A solution mixed with chemicals and a dose of radiation, the processes involved at municipal waste treatment facility is not typically designed to attack these pollutants. In 2013, a Duke University study found radiation levels downstream from a waste treatment plant 200 times greater than background levels.[7] This is because one of the most effective methods for removing radiation from water is the reverse-osmosis method; an energy intensive and costly method. Based on this, very few facilities have upgraded to this technology, capable of removing 95+% of radiation from water.

Reverse-osmosis facilities have been increasing since the acceptance of fracking. The major concern is that these plants have not been able to keep up with the demands for water quantity from the added fracking activities; resulting in the remainder overflowing into the municipal system. This problem has not been helped by only 700/160,000 of plants for processing wastewater being designed for radiation removal. Because of the limitations in the number of available facilities to process water properly, effluent from wastewater treatment facilities has been measured to contain 200x greater than background levels of radiation. While the risk to human populations remains low, these values are much higher than US allowable levels. With radiation being a hazard that cannot be perceived, even these relatively small doses of radiation have been known to cause great concern among residents.

With so few facilities able to process waste from fracking sites adequately, a variety of technologies and uses have developed to utilize the effluent. Fracking fluid in Pennsylvania has been trialed as a preventative ice solvent on winter roads. In this application, radiation infused water is sprayed across patches of road to prevent freezing[8]. This process has drawn great criticism, as many view it as simply dumping the solution into nature. These types of solutions, though, seem to be the most promising ones. This is especially true when the cost of meeting regulatory compliance is added in. While a company may choose to violate dumping regulations on fracking fluid, they will be fined $83,000 and receive bad publicity. This is in stark comparison to the $30 Million dollar upgrade to waste treatment facilities necessary to process the radioactive waste[8]. As long as the cost to process through municipal systems remains competitive, that will likely continue without costly upgrades.

As these costs and concerns are realized, attention is turned to other fluids used in less water-rich locations. One report suggested that with butane's relatively easy disposal in comparison to water that in the future, water may only be used as it is today in cooling drilling operations. Even with less concerns about contaminated water, these other fluids do bring their own issues. In one Canadian town, gelled propane caused an explosion at a fracking site that killed workers. While it has been seen that less arid regions have switched away from water as a primary fluid, there is data that suggests that fracking uses small amounts of water in comparison to other energy sources[9]. Water use is often cited as a major flaw in the sustainability of the technology. This argument, fails to acknowledge the significant water needs in the production of other energy sources. A report from the University of Texas found that a power plant switching from coal to natural gas used 25 to 50 times less water with natural gas than coal[10]. This data can be seen in the chart below from the IEA 2012 report. While shale gas appears to have the ability to use more water than other fuels on the high end, this report doesn't include recent advances in fracking technology. In addition, while difficult to measure, these reports even suggest close comparisons have been called into question[11].

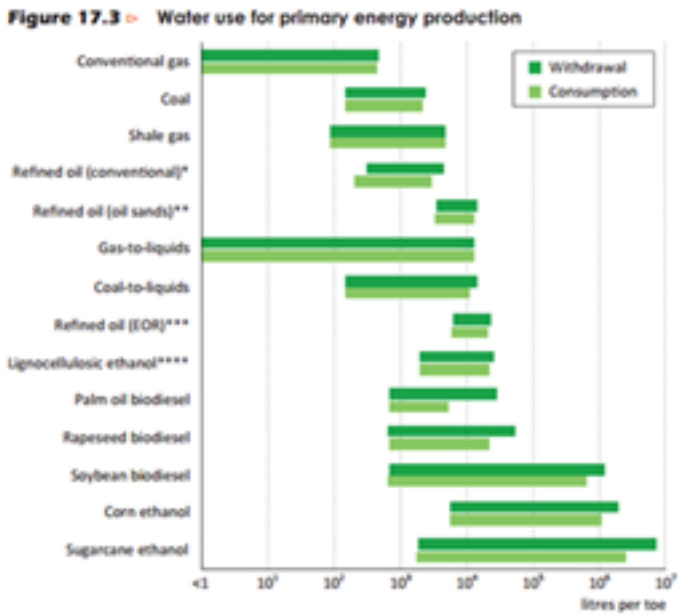

Figure 2: IEA: Water use for energy

It has been shown that fracking is known to cause pollution of groundwater and in larger known examples river effluent through well faults and poor post-processing capabilities. Looking at the energy source that fracking is attempting to replace, coal, however, we see that water in coal processing hasn't had a clean record environmentally as of recent. On a number of occasions, dammed coal ash sludge from processing plants have had failures which have resulted in large amounts of coal ash being released into rivers and other bodies of water. These incidents bring along and deposit the heavy metals and other pollutants removed from coal into the estuaries. So, while fracking might have negative impacts to water supplies, they typically are on similar to much smaller scales than those impacts from not only quantities used, but impact failures in coal processing and mining technologies and techniques.

With the outrage over taking water to be used for fracking, it is often forgotten how much water in general is used for energy production. We've seen how fracking uses the same or less water than other sources. While water plays a major role in hydraulic fracturing, coal is also significantly reliant on water resources. In addition, locations that do face future water security concerns have options to look to for non-water based fluid solutions. Looking at the numbers, it is clear that the hype on how much water is used for fracking is significantly overblown. Given a plant of 1000 kWh, the entire process of fracking and combustion would require 23.24 L of water, while a coal plant would require 530 L[12].The biggest problem with hydraulic fracturing is the post-processing of water, but looking at coal as being the fuel to be bridged from; both have significant water pollution problems.

Emissions

Although there are many issues related to the switch from coal to natural gas for power generation in the state of Pennsylvania, some of which we discuss in other sections, the most salient of these as it pertains to climate change is the relative emissions of greenhouse gases from the production and burning of these two fuels. The most prominent of these greenhouse gases are methane and CO_2. Others, such as CO, NO, SO_x, and NO_x are also of concern, but are not discussed in detail here. It should be noted, however, that emissions of these and other volatile organic compounds (VOC's) are typically less from natural gas than from coal. In this section we investigate the nature and extent of methane and CO_2 emissions from coal and natural gas production and use in electricity generation in Pennsylvania from 2006-2010, and estimate their global climatic impact.

CO_2 and Methane in the Atmosphere

CO_2 is a long-lived, well-mixed trace constituent of Earth's atmosphere, with current concentrations ~400 ppm. It is a potent greenhouse gas that absorbs and emits infrared radiation at different wavelengths than other important greenhouse gases, such as water vapor. In this way, variations in CO_2 concentrations effectively act as a control knob for saturation levels of water vapor in air. Small changes in CO_2 levels alter the atmosphere's capacity to carry water vapor. Therefore, an increase in CO_2 corresponds to an increased capacity of the atmosphere to hold water vapor, a thicker insulating layer around the Earth is produced, and higher overall surface temperatures are the result. Decreases in CO_2 levels should, theoretically, lead to the opposite effect. CO_2 is a by-product of the burning of fossil fuels, such as coal and natural gas.

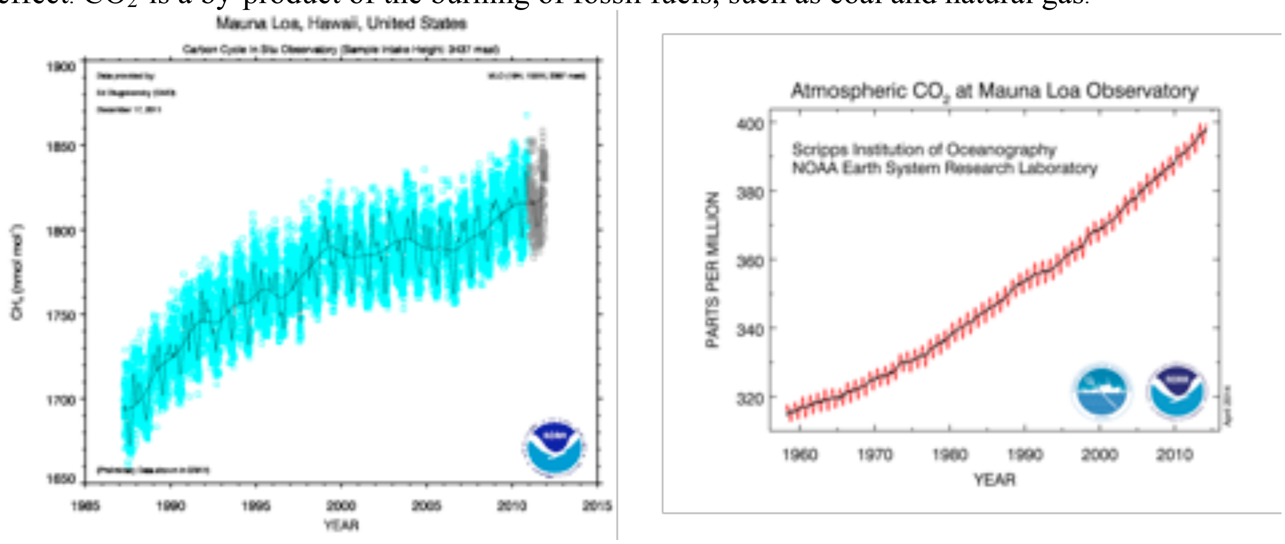

Figure 3: CO2 and methane concentrations as measured at Mauna Loa Observatory.

Methane is widely regarded as one of the most potent of the greenhouse gases. Its current concentration in the atmosphere is ~1800 ppb. Over a 100-year period, it traps 29 times more heat per mass unit than CO_2. It is less well mixed than CO_2, and variations in methane concentrations can be measured spatially. High concentrations of methane are reported over areas (both natural and human) that emit the gas. These include wetlands, landfills, livestock, coal mines, natural gas wells, etc. Chemical reactions in the atmosphere eventually break it down and eliminate its effects. It has a relatively short atmospheric lifespan of ~10 years in the troposphere and ~12 years in the stratosphere. Figure 3 shows the historical increase of both CO_2 and methane in the atmosphere.

CO_2 Emissions in Pennsylvania

CO_2 emissions are broken down by fuel type. They are further subdivided by whether they are associated with production of the fuel or with electricity generation for the state. This is an important designation because not all of the produced fuel is burned for electricity (some of it is exported out of the state and is not accounted for). By looking at both the production and electricity generation steps, we hope to get a more complete picture of the true emissions of the state of Pennsylvania.

Table 1. Calculation factors for converting coal and natural gas volumes produced/burned for energy generation to volumes of CO_2 released to the atmosphere.

CO_2 conversion factors		
	Coal (m^3 CO_2/short ton coal)	Natural Gas (m^3 CO_2/Mcf)
Production	26.6[18]	18.3[19]
Electricity Generation	1020.4[18]	39.1[20]

18. National Renewable Energy Lab Report, 1999
19. Energy Information Administration
20. Venkatesh, 2011

Using production and end use data published by the Energy Information Administration (eia.gov), and the conversion factors in table 1, the following figures give a picture of the CO_2 emissions state of Pennsylvania during the years 2006-2010. Please refer to the "emissions data" spreadsheet of the supplementary materials for the details of the calculations.

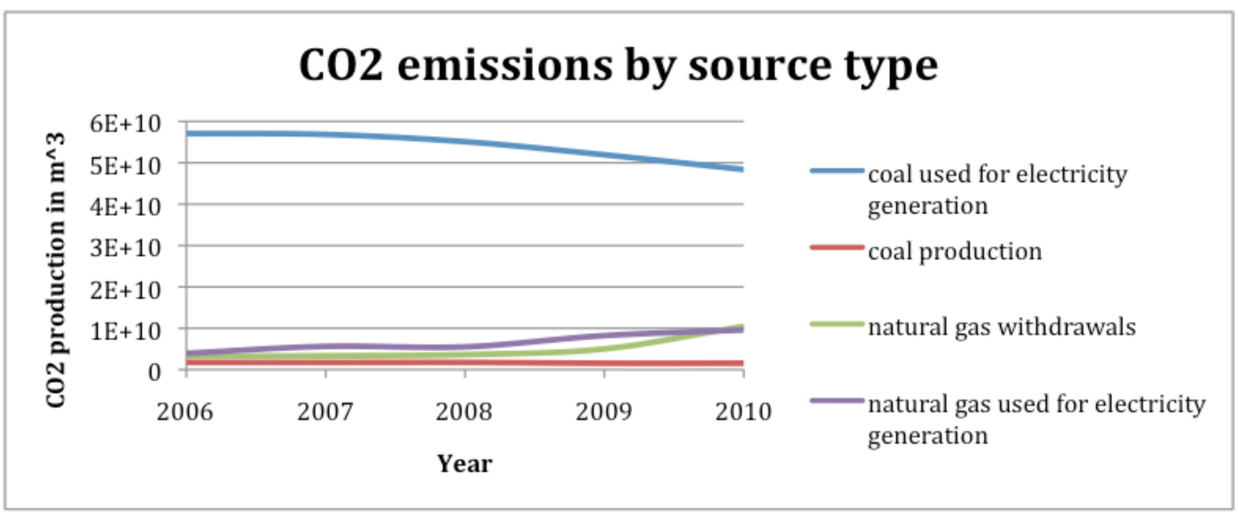

Figure 4: CO2 emissions by source type

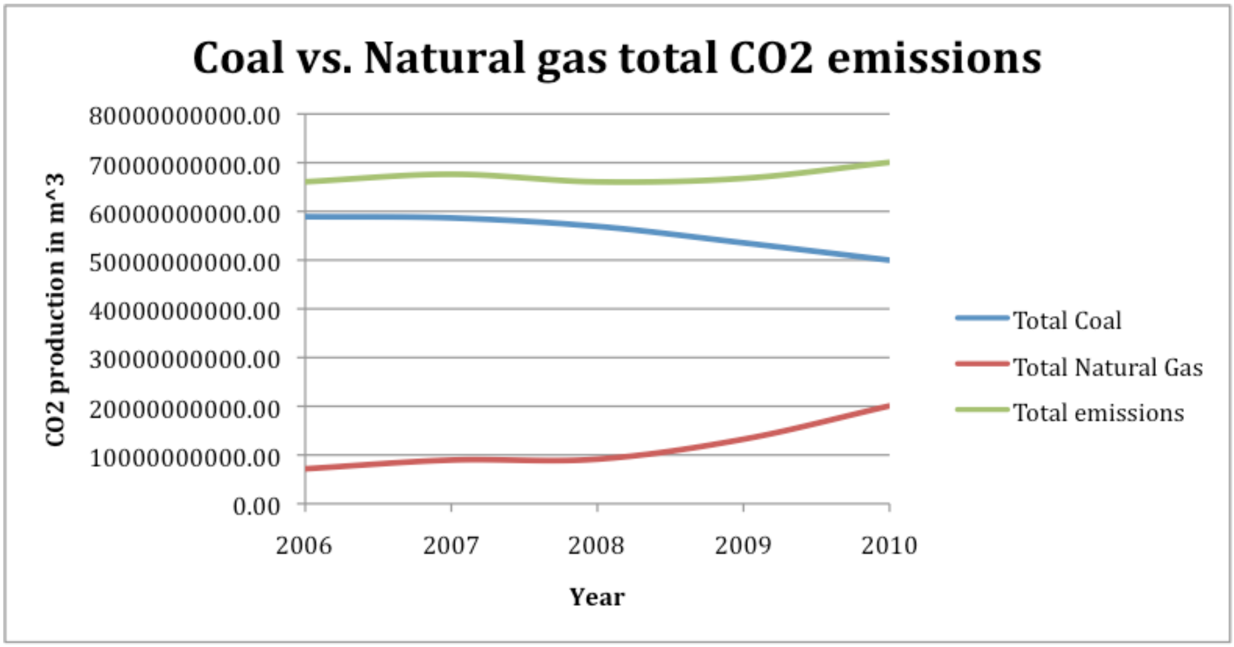

Figure 5: Coal vs. natural gas total CO2 emissions

These figures show that emissions from coal are much higher than compared to natural gas. This is logical, as natural gas is only used to produce 10% as much electricity as coal. Another key point to make is that per kilowatt-hour of electricity generated, coal releases 0.56 m^3 of CO_2 into the atmosphere, whereas natural gas only releases 0.45 m^3 of CO_2 (both production and electricity generation are taken into account). At current electricity generation rates, 3.2 billion cubic meters of CO_2 are emitted annually by coal power plants. If all coal power plants in Pennsylvania were converted to natural gas-fired electricity generation, the CO_2 emissions would be .67 billion cubic meters of CO_2 annually. That is a 21% reduction of CO_2 emissions.

Methane Emissions in Pennsylvania

Methane is released into the atmosphere during the extraction process of both coal and natural gas. Methane exists in coal seams as a product of the breakdown of organic material when subjected to heat and pressure[22]. Subsurface coal is under greater pressure than surface coal, and therefore has greater volumes of associated methane. The gas is also released to the atmosphere during the extraction of natural gas. Natural gas has many constituents, but it mainly consists of methane. Other associated gases include ethane, butane, propane, nitrogen, and pentane. Emissions of methane attributed to natural gas production are typically associated with venting practices, inefficient flaring, and leaky equipment systems. Table 2 outlines the conversion factors used in all calculations:

Table 2. Calculation factors used to estimate methane emissions from coal and natural gas production data.

Methane conversion factors		
Coal		Natural Gas
Type	(m^3/short ton)	0.42% of total production[21]
Surface coal	0.96376[18]	
Subsurface coal	2.134401[18]	

18. National Renewable Energy Lab Report, 1999
21. Allen, 2013

Using production and end use data published by the Energy Information Administration (eia.gov), and the conversion factors in table 2, the following figure gives a picture of the CO_2 emissions state of Pennsylvania during the years 2006-2010. Please refer to the "emissions data" spreadsheet of the supplementary materials for the details of the calculations.

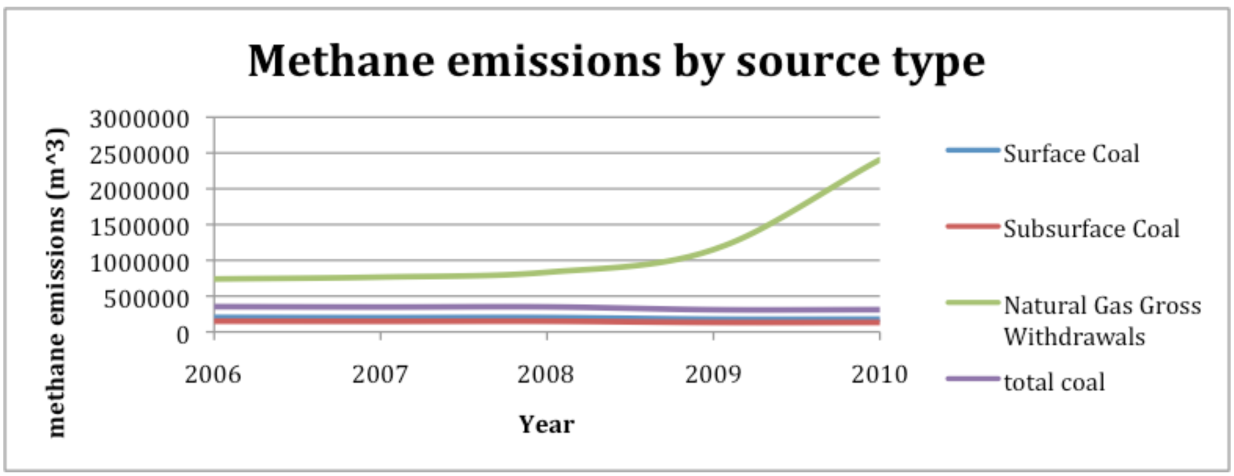

Figure 6: Methane emissions by source type

Figure 6 illustrates the fact that methane emissions from natural gas production are increasing (likely due to the increase in the use of new hydraulic fracturing techniques). When comparing methane emissions relative to electricity generated, surface coal emits 2.2e-6 cubic meters per kilowatt-hour. Subsurface coal emits 4.94e-6 cubic meters per kilowatt-hour. Natural gas emits 1.58e-5 cubic meters per kilowatt-hour. Natural gas emissions of methane are a full order of magnitude larger than coal emissions. Surface coal methane emissions are 14% of natural gas emissions per kilowatt-hour. Subsurface coal methane emissions are 31% relative natural gas[23]. A possible measure that could be taken to reduce the amount of methane emissions is "green completion" of hydraulically fractured natural gas wells. Instead of venting the newly drilled well to the atmosphere, as is currently the practice during a step in the drilling process, the well can be vented to a chamber where the natural gas is stored for later use. This process is more expensive, but effective. Other measures include preferentially mining surface deposits of coal, capturing methane from subsurface wells, or increasing production of natural gas at the expense of methane.

Emissions Conclusion and Recommendations

Coal as an energy source for electricity generation produces significantly more CO_2 per unit energy than natural gas. Displacing coal-fired power with natural gas-fired power could reduce CO_2 emissions by ~21%. A conversion to natural gas would, however, severely increase methane emissions. Methane emissions could be reduced if further measures are taken during the natural gas recovery process to curb venting practices and equipment malfunction/leaking by monitoring or quality control.

Policy

Since 1859, there has been over three hundred and fifty thousand oil and natural gas drilling wells in the state of Pennsylvania; however, it was not until 1956 that Pennsylvania first started to regulate the drilling. This was done through the state's Oil and Gas Act. This act was established through DEP's Office of Oil and Gas management, which is responsible for the statewide oil and gas conservation and environmental programs. This office develops these programs and policies to regulate, protect, and facilitate the safe exploration, development, and recovery of oil and gas reservoirs[24]. Pennsylvania's DEP continues to enact additional extensive rules to legislation that that are aimed to protect the commonwealth's natural resources and environment. Pennsylvania's fracking regulations are some of the most multi-layered and comprehensive in the country.[25]

In February 2012, Act 13, also known as the Impact Fee Law, was passed by the state legislature. It reformed the Oil and Gas Act, and restored state regulatory power. Some of the Act's requirements include: 1) the expansion of the drilling contamination liability space from a 1,000 to 2,500 foot radius per well, 2) increase of civil penalties for violations of regulations, 3) disclosure of fracking chemicals to the DEP and publication of these disclosures on FracFocus.org, and 4) charging drillers an impact fee. The amount of the fee was set to vary with time and fluctuating natural gas prices, along with sixty percent of the revenue to stay at local level, which consists of counties and municipalities hosting wells. The other forty percent goes to numerous state agencies associated in the regulation of drilling and to the Marcellus Legacy Fund, which is used for environmental and infrastructure projects around the state[26]. On November 2013, it was reported that the fee generated over four hundred million dollars[27], however, even with this monetary gain, parts of Act 13 was ruled unconstitutional in December of 2013. The Pennsylvania's Supreme Court agreed with the municipalities concerns about the Act violating the Environmental Rights Amendment to the Pennsylvania Constitution. The Environmental Rights Amendment is a zoning law that was passed on February 8, 2012 that determined that zoning provisions violated the Amendment of the state constitution that guarantees the people of Pennsylvania the right to clean air, pure water, and to the preservation of the natural, scenic, historic, and esthetic values of the environment[28]. Act 13 placed limits on local zoning, which violated the municipalities'' substantive due process[29]. It eliminated zoning authority and land use planning from municipalities over oil and gas extraction. The natural gas drilling industry argued for statewide zoning consistency for they believe in order for the business to grow, there must be stability and regularity. On the other hand, some people argued that the authority on zoning given to individual communities is the only way they can protect their surface areas[29]. The ruling is believed to have intensified the issue of localities vs. state in terms of who has control over fracking. More communities are trying to pass local bans on fracking; however, state governments and corporations are legally challenging these efforts. This is also a problem with the Delaware River Basin Commission (DRBC) Moratorium.

The DRBC is an organization made up of governors form various states and delegates from the Army Corp of Engineers that represent federal interests. It was established in 1961 and it was aimed to coordinate water management in the Delaware River Basin, which stretches 330 miles across parts of Pennsylvania, New York, New Jersey, and Delaware. They manage water quality, withdrawals, droughts, floods, conservation and permitting for the river and its tributaries. It is funded by the states, the federal government, permit fees, fines, as well as public and private grants. Due to the concerns over the impact on water quality and withdrawals that arises from hydraulic fracturing, along with other legislative issues within the states, in the spring of 2010, the DRBC voted to hold off any decisions regarding drilling in the Basin until new regulations are adopted[30].

The Susquehanna River Basin Commission (SRBC), similar to the DRBC, is a committee whose purpose is to manage water resources. They are a federal-interstate compact commission created by the Susquehanna River Basin Compact between the states of Pennsylvania, New York, and Maryland. The law was created in 1970, and due to the River's location in the Marcellus shale, there has been some controversy over hydraulic fracturing. On March 2012, there were protests due to the SRBC approval of 46 water withdrawals, 40 of which were for fracking. People were arguing that drilling is "a clear and present danger to the public health of the citizens of Pennsylvania.[31]" Although there has been no confirmed or scientifically proven cases of contamination of Pennsylvania water due to fracking, the protestors argued that the drilling contributes to an increase in methane levels and chemical polluted water based on a case that involved a drinking water aquifer being tainted with chemicals in Wyoming[31]. The SRBC responded stating that the gas companies have been using less water than they are permitted to use and they have been using less fresh water due to their use of recycled "flowback" from previously drilled wells[31]. However, due to the resistance, the Commission approved of several water withdrawal permits. On another note, in regards to the role of the federal government, there is not a clearly defined role they partake in terms of the regulation of hydraulic fracturing. The EPA has announced that new federal standards for fracking are now being developed, however, the main authority on this issue is passed onto the states and all of the member parties of Maryland, Pennsylvania, and New York, have to approve of the laws and regulations they place on the Susquehanna River[32].

Another organization that involved various states to work together to help protect a water source is the Great Lakes-St. Lawrence River Basin Water Resources Council. This council, in December 2008, created a compact, called the Great Lakes—St. Lawrence River Basin Water Resources Compact, that is an agreement among the Great Lakes States of Illinois, Michigan, Minnesota, New York, Ohio, Pennsylvania, and Wisconsin. The compact provides a framework for each state to enact programs and laws protecting the Basin, and the fish and wildlife surrounding it. There have been individuals who believe that fracking in Pennsylvania could be responsible for a large fish kill due to its impacts it has already had on its fisheries[33], which is one of the reasons why the regulations on hydraulic fracturing came into discussion. However, due to the huge regulatory gaps at the federal, state, and provincial levels, there is much more work that still needs to be done in regards to legislation of fracking in the Great Lakes-St. Lawrence River Basin.

Pennsylvania's use of zoning laws to increase municipal power over fracking has led to controversy over past and pending legislation, however, there are indeed current established regulations. For example. in terms of drilling, oil and gas companies must submit a detailed report to the state's DEP. The report must include detailed information that is required to carry our environmental risk analysis. This information includes the well depth and location of where they plan on drilling, as well as the related geological information, such as the nature of the surrounding rock formations, and juxtaposition to groundwater and local water supplies. Additionally, "drillers must submit a deposit or bond to the state as security against violation of environmental regulations and restrictions[25]," as well as not drill within 200 feet of drinking water supplies, within 100 feet of any surface water, or within 100 feet from any wetland size greater than one acre[25]. On another note, according to the Pennsylvania Oil and Gas Act, drillers must replace or resolve any loss of drinking water due to contamination from drilling operations. They are responsible for contamination if it occurs within 1,000 feet from the well in question and within 6 months after well completion. Drilling companies. However, can challenge the claims of their responsibility for contamination. They may do this if: 1) the pollution existed before the drilling befell, 2) the landowner or water purveyor refused to allow the operator access to conduct a pre-drilling water test, 3) the water supply was not within 1000 feet of the gas well, 4) the pollution occurred more than six months after completion of gas well drilling, or 5) the pollution occurred due to an alternative cause that does not deal with gas well drilling[25]. In addition to water testing and drinking water replacement, water quantity is also of key importance. The Oil and Gas Act necessitates companies to restore or replace drinking water supplies that are diminished by gas drilling activities. The loss of water quantity due to fracking is on the hands of the drilling companies. Additionally, the DEP, through the Water Resources Planning Act, requires that extractions of over 10,000 gallons per day of water, must be reported to the DEP and all withdrawals due to drilling in the Marcellus Shale must be registered with the Susquehanna River Basin Commission or the Delaware River Basin Commission[25].

The current policies in terms of surface disturbances in Pennsylvania include the requirement of submission of an erosion and sedimentation plan to the DEP in advance to drilling. This is because of the concern that groundwater supplies could be affected by erosion and sedimentation caused by roads, drilling pads, and pipelines that are constructed and ongoing, which require frequent trips to transport machinery, fluids, and supplies[25]. The state also requires drilling companies to plug in wells after production ends and that the part of well casing protecting the groundwater must be maintained and "its integrity verified before the well is further filled with nonporous material[25]."

Natural gas, in comparison to other fossil fuels, is efficient and clean for they emit 80 percent less nitrogen oxides, less sulfur dioxide, no mercury and few particulates. In Pennsylvania, according to the DEP, air pollution from the state's natural gas industry represents a small fraction of the state's total emissions in 2012. There has been a decline in air emissions since natural gas drilling increased in 2008. For example, since 2011, there has a 17.21 percent decrease on sulfur dioxide and a 1.09 percent decrease of nitrogen oxides[34]. Nonetheless, there is still concern over air quality and greenhouse gas emissions. According to the Environmental Protection Agency (EPA), natural gas systems are one of the major methane emitters in the U.S, however, due to lack of data, this issue being reexamined. Recently, the EPA has finalized New Source Performance Standards, which are set to take place in 2015, for natural gas hydraulic fracturing operations to reduce smog-forming air pollution and harmful air toxins[35]. Additionally, the EPA has been examining fracking under the Clean Air Act. On April 17, 2012, they adopted rules on air emission that come from oil and gas operations. These rules require hydraulic fracturing operators to use reduced emissions completions, which are reduced flaring or green completions that captures gas that may escape during hydraulic fracturing[36].

As of May 2012, there have been at least 119 bills in 19 states that have been introduced to addressing hydraulic fracturing. Those whom have enacted legislation include, Indiana, Maryland, New Jersey, North Carolina, Pennsylvania, South Dakota, Tennessee, Utah and Vermont. State legislatures are working to improve public health and environmental concerns, as well as take advantage of the economic potential that natural gas drilling has to offer. The requirement of chemical disclosure has been proposed to at least 9 states, including Michigan, New York, Pennsylvania, and California. Wyoming was the first state to require full public disclosure of fracking chemicals, and Texas became the first to enact legislation. Additionally, Colorado requires drillers to disclose not only the names of the chemicals, but also the concentrations and some states[35]. On the other hand, in terms of water use and quality legislation, there has been at least six states that have considered bills and resolutions to protect public water supplies, limit water withdrawal, and require water quality testing and regulate waste disposal. Some of these states are Indiana, whose bill required certain drilling operators to submit an environmental compliance plan for review and approval had failed, Michigan, New York, Pennsylvania, and West Virginia, who also had a failed bill. Their bill required "gas well operators to submit information to the Office of Oil and Gas—such as anticipated withdrawal, type of water source, planned management of wastewater, lists of additives, and more[37]." In regards to air quality, Arkansas was the only state that attempted to pass a bill to protect air quality in the vicinity of natural gas drilling fields, however, it was withdrawn. In dealing with fracking moratoria, which is legislation trying to ban hydraulic fracturing, New York, West Virginia, Maryland. And New Jersey have attempted passing bills. New York has the most pending bills out of those states[37]. As fracking continues its expansion legislative action is more likely to increase. States continue to work towards balancing the economic benefits of accessing new resources with protecting public health, drinking water, and the environment.

Business

Because of low natural gas prices, stagnant coal prices, and environmental regulations many energy companies are making the switch from coal-fired to natural gas-fired power plants. Pennsylvania, in particular has seen a major shift in energy supply. In the last two years, natural gas production has more than quadrupled in the Marcellus Shale region, placing Pennsylvania in the top ten producers of natural gas annually. Historically, Pennsylvania relied on interstate pipelines from the Gulf Coast to supply natural gas, but with increased Marcellus Shale production, they are able to meet its own demand and export gas out of state via pipeline.[19] From the perspective of energy companies, making the switch to natural gas depends on capital costs, operating costs, emissions control requirements and long-term profit sustainability.

Four critical regulations proposed recently are having major effects on coal-fired plants. These regulations include the 1) the Cross-State Air Pollution Rate (CSAPR), prohibiting certain emissions of air pollutants, 2) the National Emissions Standards for Hazardous Air Pollutants from Coal and Oil Fired Electric Utility Steam Generating Units (Mercury and Air Toxics Standards-MATS), 3) Cooling Water Intake Structures at Existing Facilities, which establishes requirements for water use for cooling purposes and 4) the Disposal of Coal Combustion Residuals from Electric Utilities regulation (CCR), which monitors the disposal of combustion residuals.[38]

Companies faced with these regulations have a few main options including retrofitting existing coal plants with pollution control equipment, retiring coal plants, or converting plants to natural gas-burning.

The cost of retrofitting existing plants in compliance with EPA regulations is substantial, and is a major deterrent for companies to continue operation of their coal plants. Between 2007 and 2011, coal-fired power plant owners in the United States invested over $30 billion in scrubbers to comply with the new regulations. Plant operators in Ohio, Pennsylvania, West Virginia, Maryland and Georgia made 43% of these investments, spending a total of $13 billion.[39] Pollution control equipment costs vary from plant-to-plant, therefore it is difficult to calculate how much an average pollution control system costs coal plant operators. For example, Homer City Generating Station, the second largest coal plant in Pennsylvania, plans to add $700 million worth of scrubbers to keep their 40-year old plant in operation[40].

Other companies, however, see pollution control equipment as a sunk cost and either retire their coal burning plants or convert them to natural gas. As of May 2012, 288 coal generators announced plans to retire or to convert to natural gas. Figure 7 shows that operating costs of 86% of these retiring coal generators are not able to compete with the operating costs of existing natural gas generation plants[41]. Through 2020, the US Energy Information Administration estimates that over 20 Gigawatts of Mid-Atlantic & Ohio River Valley coal-fired plants will retire[42]. Recently, FirstEnergy Corp. deactivated two of its Pennsylvania plants that had capacity to generate 2,080 megawatts of power. Both plants were over 40 years old and were in need of expensive upgrades to limit air and water pollution[43].

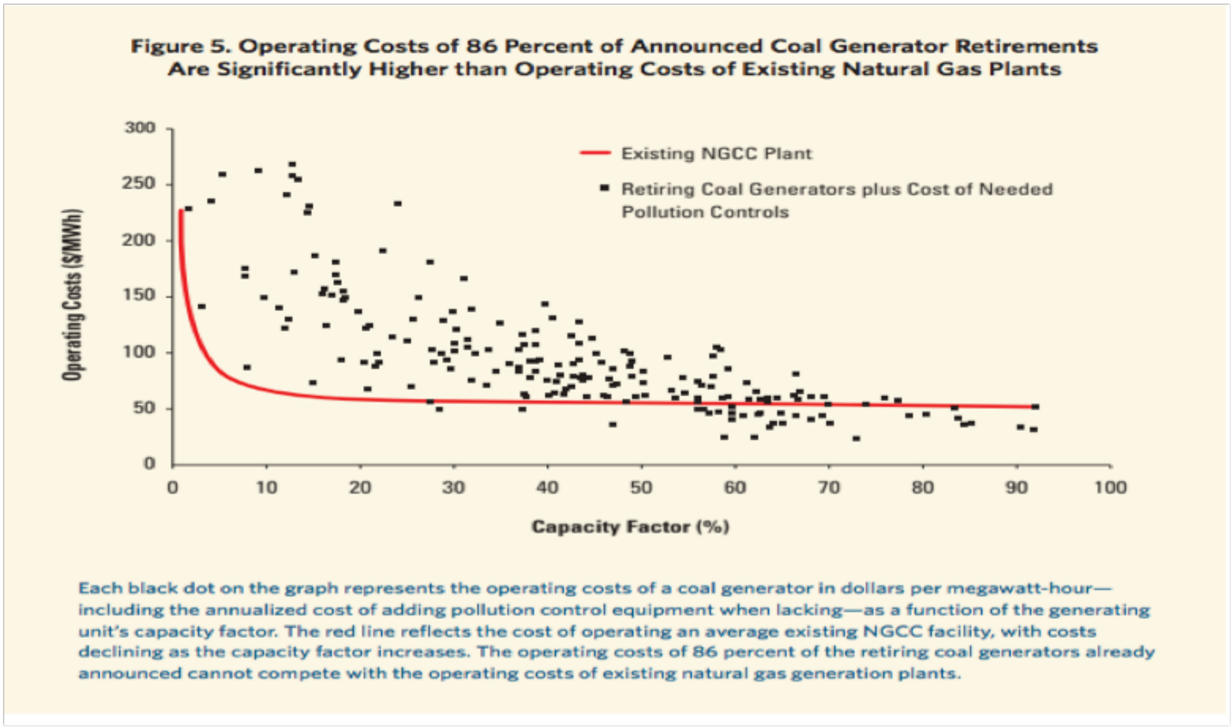

Figure 7: Operating Cost of Coal versus Natural Gas

Instead of or in addition to retiring plants, some companies are making the switch to natural gas. Converting plants to natural gas requires pipeline construction, revenue metering station installation and rights-of-way, which can require funds anywhere between hundreds of thousands of dollars to more than $1 million per linear mile of pipeline to the site[44]. As of 2011, Pennsylvania had 8,600 miles of large diameter interstate and intrastate natural gas pipelines, making them the 8th highest in the United States[45]. Substantial infrastructure is already in place in the region, making the switch from coal to natural gas less costly, and therefore more attractive for energy companies in Pennsylvania. Although an extensive pipeline infrastructure already exists, construction of thousands of miles of new pipelines in Pennsylvania is expected because of the development of the Marcellus Shale gas region. The new pipeline infrastructure introduces new jobs in the area, appealing to residents and policymakers[46]. Pipeline rights of way must be secured from private and public landowners, also providing economic benefits to residents, but adds to the expense for private natural gas companies.

Another key consideration for energy companies is the long-term sustainability of profits, supply certainty, and price projections. In 2013, City Gate natural gas price in Pennsylvania was $5.14/MMBtu, which was slightly above the national average of $4.91/MMBtu. On the other hand, in 2013 the coal prices for electricity generation in Pennsylvania was $2.55/MMBtu, while the US average was $2.44. The Energy Information Association projects national natural gas prices to be around $4.11/MMBtu, while national coal prices will be closer to $2.36/MMBtu in 2015[19]. Increased production in the Marcellus area contributes to the falling natural gas prices in the region, and prices often fall below Henry Hub prices. Therefore, the EIA predicts that drilling activity may move away from the Marcellus and back into the Gulf Coast, where prices are closer to Henry Hub pricing. However, as demand for natural gas increases, this will drive the price up, making natural gas less appealing for utility companies and investors.

In 2011, total electricity consumption for the state of Pennsylvania was 4,414 Trillion Btu, while the consumption of natural gas was 1,000.5 billion cu ft, representing about 4.1 percent of total US natural gas consumption. Production of natural gas in the state was 2,256,696 million cu ft, or 8.9 percent of total US production[19]. Demand for natural gas both nationally, and in Pennsylvania can be expected to increase as more coal-powered plants retire.

An important consideration is the long-term supply and viability of using natural gas in replacement of coal. In Pennsylvania there are currently 55,136 natural gas producing wells, which accounts for 11.4 percent of total wells in the United States. Additionally, there are 36 trillion cu ft of proven dry natural gas reserves[19]. Based on current total Pennsylvania electricity consumption levels and proven reserves, if Pennsylvania displaced all other fuel sources with natural gas, they would be able to supply 8.5 years of energy needs to state residents. On the other hand, at current natural gas consumption levels, and business as usual, proven reserves would have the ability to supply 36 years of energy to Pennsylvania residents (See Table 3 below for a breakdown of supply calculations).

Total Reserves[19]	36 trillion cu ft.
Cubic Feet to Btu[19]	1,027 Btu in 1 cu ft.
Total Supply	36 trillion cu ft x 1,027 = 36,972 trillion Btu
Total Electricity Needs in PA[19]	≈ 4,414 trillion Btu
Natural Gas Needs- Business As Usual[19]	≈ 1,001 trillion Btu
Years NG can Supply Total Energy Needs	36,972 trillion Btu/4,414 trillion Btu ≈ 8.4 years
Years NG can Supply Business As Usual Needs	36,972 trillion Btu/1,001 trillion Btu ≈ 36 years

Table 3: Natural Gas Supply Calculations

Recommendations

The use of hydraulic fracturing has presented a case in which fracking may be used to extract natural gas, a possible fuel alternative, in terms of energy usage. Although there many concerns associated with the process, the findings and figures in this study support the conclusion that fracking could be a possible alternative to present day energy sources. For the purpose of this study, the state of Pennsylvania is chosen as a case study in order to understand the different aspects, such as water usage, gas emissions, policy, and business, hydraulic fracturing has on the area. The findings given in this study are used to give Pennsylvania's Department of Environmental Protection a comprehensive overview of fracking from a sustainability perspective.

The water usage in Pennsylvania from hydraulic fracturing is one factor of consideration for implementing fracking into local communities. Findings support that in future climatological scenarios that more precipitation will be available during the winter and spring months of the year (EPA). With the amount of water being used in fracking equaling a 17 days' amount of precipitation for Pennsylvania, it is possible to sustain operations of hydraulic fracturing in the state. However, it should be cautioned that this process might not be as effective in other regions like the Central Plains because future predictions have suggested significant decreases in precipitation throughout the year in that area (EPA). The possible alternatives for such drastic changes would be the incorporation of other liquids such as butane or liquid petroleum. Pennsylvania can consider these alternative brines, and this would reduce the 4 to 8 million gallons of water that is currently used for this process.

Another perspective of water usage is the concern of contamination to local-drinking waters in the area. Efforts have been made to reduce the amount contamination in local water through different processes, such as reverse osmosis. This process is fairly costly for factories to employ, and this would cause minor facilities to avoid such protocols for pollution reduction. The state of Pennsylvania could offer support to facilities by offering incentives that would allow facilities to upgrade their equipment to implement such cleaning methods.

The emissions from hydraulic fracturing shows promise in terms of reducing the amount of CO_2 that is given off from the process. Through calculations that are provided in the emissions section, it is clear that the conversion of all coal power plants to natural gas-fired plants would reduce the total CO_2 emissions in Pennsylvania by about 21%. The Department of Environmental Protection should take this into consideration because just small conversions of coal-fired power plants can lead to reduced emissions from the state as a result. Although the total conversion of these plants would be the most beneficial, there is another gas under consideration that may hinder such results.

Methane is another potent greenhouse gas that is emitted during the burning of natural gas. As shown in the figure for methane emissions by source type, the amount of CH_4 released into the atmosphere by natural gas is a magnitude higher than coal emissions. With the total conversion of coal-fired power plants to natural gas-fired plants, this amount of CH_4 emissions would increase drastically over time. In an effect, this would negate the CO_2 emission reductions due to CH_4 having a impact on climate change over 20 times greater than CO_2 in a 100-year period.[36] This would cause great conflict in trying to manage the CO_2 emissions budget because hydraulic fracturing would cause more CH_4 to be released throughout this process.

In order to combat the possible increase in CH_4 reductions from hydraulic fracturing, new approaches are needed for regulating the greenhouse gas. One method of recommendation is through "green completion" which sequesters the CH_4. This ensures that lesser amounts of methane are emitted into the atmosphere as a result of hydraulic fracturing. The results of such implementation may reduce emissions of CH_4 by 50 Mg for each well.[22] Green completion is the most preferred method of having control over the CH_4 emissions, and it implementation would have the most beneficial results in terms of climate change. With such regulations being implemented by different policies, it is possible to see such technologies being useful in CH_4

reductions for hydraulic fracturing. The reduction in both these greenhouse gases would make hydraulic fracturing a beneficial source of energy in the future.

The policies associated with hydraulic fracturing has shown great priority in protecting citizens from possible side effects of fracking. There have been many policies, such as Act 13 and the Safe Water Drinking Act, that have been implemented in the state of Pennsylvania. Further action to create and regulate hydraulic fracturing is necessary in order to ensure citizens and businesses an equal opportunity to be protected while this process is occurring in different communities. Working with other states in the region helps in creating regulations that would be applied in possible cases of water reduction from climatological events like droughts. Working with other states and regions with little water resources available enables the state of Pennsylvania to be prepared for water shortages, and the ability to find environmentally friendly alternatives gives greater support for implementing hydraulic fracturing into the state. The overall purpose for creating these policies is to find the balance between the economic benefits and protection of public health, drinking water, and the environment. Further analysis from a business perspective enables more clarity on the subject of implementing policy for hydraulic fracturing.

The economic benefits of hydraulic fracturing is important for plants that are planning to convert from coal-fired power to natural gas. As stated before, the benefit of switching to natural gas decreases the operating cost, as well as enable higher efficiency within the plant itself. With such high availability in natural gas from the Marcellus Shale, the price of natural gas decreases as a result. The affordability of natural gas would make it viable source for energy production in the U.S., and it is recommended to create regulations that ensure the maintenance of such a resource. Communication with companies, the department, and the citizens is necessary for natural gas to be a viable bridge fuel for coal and oil.

Conclusions

Hydraulic fracturing has been one of the most controversial environmental topics in terms of energy production. Many concerns with hydraulic fracturing involved water usage and greenhouse gas emissions that are done while this method of extracting natural gas is occurring. The purpose of this study is to provide background on different aspects of hydraulic fracturing, and the effects it has on climate change as well as human sustainability. With such drastic changes in the climate occurring, it is advised to find other possible ways of energy production that decreases the environmental impacts in a reasonable and affordable way. In the context of this study, bridge fuel is a term associated with humans finding alternative fuels for coal and oil in manner that temporally reasonable.

In conclusion, hydraulic fracturing is a valuable process for extracting natural gas from the shale reserves that are underground. The amount water that is used for the process is significantly smaller than the amount that is used by coal for energy production. The reduction in the amount of CO_2 emissions is beneficial with reductions around 21% of current emissions. Although there are increases in the amount of CH_4 as a result of natural gas burning, technological methods such as green completion can help in regulating the amount CH_4 that is released into the atmosphere. Policies and business is vital for such implementation of hydraulic fracturing because it is the citizens and companies that make the largest impact on this issue. More research and findings are needed to give better support for hydraulic fracturing; however, this study serves as one of the efforts made to support hydraulic fracturing for use in the future.

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