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Marcellus Shale: Cementing and Well Casing Violations

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Cementing and Well Casing Violations

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Although this project was a collaborative group effort, the writing of the project was generally done individually or in teams of two or three. Multiple revisions of the report were completed by all team members. The main author(s) of each section is listed below:

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VI. Abstract

Natural gas extracted from shale formations is one of the fastest growing sources of energy in the United States. Our IQP analyzes public data regarding regulatory violations related to the casing and cementing of shale gas extraction wells in the state of Pennsylvania. Computer based data analysis programs including Microsoft Excel and MATLAB were used to generate visual representations of the data, which allowed our group the ability to more easily identify trends. Our group also interviewed experts on the shale gas industry in order to gain a more complete understanding of the issues at hand. These specialists included petroleum engineers from drilling companies such as Range Resources, employees at U.S. government agencies such as the Department of Energy (DOE) and the Environmental Protection Agency (EPA), and academic experts from institutions such as Cornell University. After these interviews and a thorough analysis of the available data, our group recognized and provided explanations for trends in the data. Some noteworthy trends identified by the group included the clustering of violations in the north-central region of Pennsylvania, and the fact that some companies appear to operate with a lower level of cementing and well casing violations. The group also identified specific areas which may need continuing research including the way that well sites are chosen for inspection and the effects of drilling through younger, shallower hydrocarbon formations in order to access the Marcellus Shale. Our final report was submitted to the DOE for use in their continuing research.

VII. Executive Summary

The Marcellus Shale, located in the northeastern United States, is one of the most promising domestic shale plays. “On March 31, 2011, President Barack Obama declared that ‘recent innovations have given us the opportunity to tap large reserves – perhaps a century’s worth’ of shale gas” (Secretary of Energy Advisory Board , 2011). The Marcellus Shale has been estimated to contain the natural gas energy equivalent to eighty six billion barrels of oil (The Gas Dilemma, 2011, p.41). This vast quantity of underutilized resources provides a promising source of relatively clean domestic energy. The fact that natural gas is inherently found in the shale formations of the United States means that America has the potential to slow its import of foreign fuels and become less dependent on other countries for energy resources. Recent advances in technology regarding the extraction of natural gas from domestic shale formations, primarily the combination of horizontal drilling and hydraulic fracturing innovations, have enabled the shale gas industry to grow rapidly during the last few years.

Along with the many positive effects that can accompany drilling in the Marcellus Shale, come significant environmental concerns. Many of these concerns relate to methane migration due to insufficient isolation of the wellbore. When the wellbore is not sufficiently isolated, methane gas from either the target formation or shallower gas bearing formations may be allowed to rise towards the surface. This process is referred to as methane migration. In some situations, methane migration can possibly result in the contamination of groundwater. Regulations have been put in place at the state level, which are aimed at ensuring proper well construction and mitigating methane migration. Poor cementing and casing practices have been associated with the loss of wellbore isolation and the possible migration of methane. Inspectors examine well sites to ensure proper cementing and well casing practices, among other things.

When violations are noted, they are recorded and made public as part of a spreadsheet on the Pennsylvania Department of Environmental Protection's (DEP) website. Since 2008, over 1,400 regulatory violations have been recorded in the Marcellus Shale region (Legere, 2010).

The purpose of our IQP research project was to analyze this public data regarding regulatory violations related to the casing and cementing of shale gas extraction wells in the state Pennsylvania. Our group used computer based data analysis programs, including Microsoft Excel and MATLAB, to generate visual representations of the data. This approach allowed us to produce a set of charts reflecting noteworthy trends in cementing and well casing violations. In order to gain a more thorough understanding of the issues at hand, our group also interviewed experts on the process of shale gas extraction. These specialists included employees at government agencies such as the DOE and the EPA, a petroleum engineer from Range Resources, and an expert from Cornell University. Through a thorough examination of the existing data, our group identified correlations between well casing and cementing regulatory violations and factors such as the company involved, geographic location, or drilling practices used. Our group also came up with possible causes for these trends and identified areas which need further research.

Based on the analysis of the data and the information gained through interviews and literary sources, our group identified trends related to cementing and well casing violations. Some of the more noteworthy trends included the clustering of violations in the north-central region of Pennsylvania and the fact that some companies appear more likely than others to incur cementing and well casing violations. It is possible that the clustering of violations in the northeast region of Pennsylvania is due to a higher concentration of shallower gas bearing formations in that area. Shallower gas bearing formations can cause problems when drilled through due to the fact that gas can escape during the cementing process and create channels in the cement, which may act as possible pathways for methane migration.

The group found that differences existed between the state laws and regulations of Pennsylvania and West Virginia. Although some of these differences may relate to differences in state geology, the group suggests that further research be done in this area to develop a set of best practices that can be implemented throughout the Marcellus Shale region. Also, due to the fact that drilling through younger, shallower gas bearing formations to access the Marcellus shale can cause the release of gas and lead to an incomplete cement seal around the well casing, further research should be done in order to find a solution to this issue. Another major area that our group deemed needed further research was the way well sites are selected for inspection. Some inspectors stated that this process was a random selection of well sites while other sources indicated a risk based computer program may assign inspectors to certain well sites.

The group submitted these findings to the United States DOE for review. The analysis focused principally on well casing and cementing violations in order to inform operators and policymakers alike about potential pathways for advancing safe and sustainable shale gas operations. In addition, these insights and recommendations provided information on how to direct further research aimed at minimizing the negative effects of shale gas extraction on both the environment and local communities moving forward.

1. Introduction

In the twenty first century, energy has an integral role in almost every aspect of modern society. Whether this energy comes from oil, coal, nuclear reactors, renewable resources, or natural gas, the sources of the energy that we so heavily depend on are more important than ever. The import of foreign fossil fuels into the United States has become very important due to the fact that domestic reserves of oil are unable to satisfy the country's demand. This dependency has caused controversy throughout the United States and has been a key topic in many political debates. There is a growing movement throughout the country to lessen our dependence on foreign oil by developing sustainable alternative energy sources and further tapping into the reserves of natural gas, coal, and oil found throughout the United States.

Serious problems and concerns have been introduced by the rapid development of unconventional oil and gas resources in the United States. Despite these concerns, the domestic natural gas industry has continued to expand over the last few years. One of the most promising sources of natural gas in the United States is the Marcellus Shale. The growth of industry in the Marcellus Shale has been evidenced by an increase in exploratory drilling and promising production returns in recent years. Despite the economic, environmental, and political benefits offered by the growing use of shale gas, the drilling process itself has introduced a new set of serious environmental and safety concerns that haven't always been properly addressed. In particular, inadequate cementing around well casings has been shown to allow methane migration (Xia, 2010). In addition, the threat of ground water contamination has not been fully investigated. In these difficult economic times, many states and localities have lacked the resources, manpower, and in some cases, the expertise to keep up with the fast pace of unconventional natural gas development. The EPA is currently ramping up regulatory efforts through technical studies, guidance documents, rulemaking proposals, and enforcement initiatives in response to these growing areas of concern.

Shale gas development isn't entirely new, but the pace of these developments has recently increased. These hydrocarbons have been harvested domestically from the Barnett Shale in Texas for over three decades. The regulations implemented by the state of Texas to govern the extraction of shale gas have served as a model for the regulations being implemented Marcellus Shale states. Under the current, pre-existing state regulations, natural gas operations focused in the Marcellus Shale have continued to grow at a rapid rate. Drilling companies are trying to extract shale gas as quickly as possible in order to maximize their economic gains. This fact, in combination with the unique geological features found in the Marcellus Shale, has led to many regulatory violations. These incidents have had negative effects both on the environment and the public (Marcellus Shale Fire, 2011). Some of these violations may have caused methane contaminated drinking water, explosions at drilling sites, and failures of the cement casings of some wells.

Currently, different states have different regulations and competing drilling companies employ different practices. There is no set of regulations or procedures in place to be used as model standards. Therefore, further research needs to be done in order to clarify which procedures work best and where more research is needed. In conclusion, there are currently no standardized best practices that can enable all companies, government agencies, state governments, and local communities to coordinate these operations in a safe and efficient manner. Having a thorough understanding of the challenges associated with ensuring the integrity of well casing and cementing could help the United States natural gas industry to grow and prosper in a safe, healthy, and environmentally friendly way.

The purpose of our IQP research project was to analyze public data and identify trends concerning the regulatory violations associated with well casing and cementing. Our group examined existing data to identify correlations between cementing and well casing violations and factors such as the company involved, geographic location, or drilling practices used. The group also interviewed pertinent individuals from drilling companies, government agencies, as well as other experts in the academic field in an attempt to gain an understanding of the trends that we observed in our data analysis. This approach allowed us to produce a set of charts reflecting noteworthy trends in cementing and well casing violations. The group also came up with possible causes for these trends and identified areas which need further research. Our results aim to assist the DOE in their effort to decrease or eliminate problems such as groundwater pollution and the migration of methane due to well casing failures. Ultimately, this will allow the valuable natural gas stored in the Marcellus shale to be harvested safely and the United States shale gas industry to continue to flourish.

2. Background

Shale gas is currently a rapidly expanding part of a very large energy market. New drilling techniques and technological development, including the combination of horizontal drilling and hydraulic fracturing, have allowed the natural gas stored in shale formations to be harvested at an economically recoverable rate. The Marcellus Shale is among the world's largest shale gas reserves. Drilling for natural gas in the Marcellus Shale could have many positive implications with respect to the economy, the environment, and energy politics worldwide. However, the drilling and extraction process has been tied to incidents methane migration (Osborn, Vengosh, Warner, & Jackson, 2011). Also, there have been growing reports of regulatory infractions related to well casing and cementing. Understanding the correlations between such infractions and factors such as geography, geology, drilling company practices, well casing specifications, and cementing requirements will provide keen insights to policymakers, regulators, industry operators, and other stakeholders seeking to successfully, safely, and sustainably develop shale gas resources.

This section of our paper delves into the background of our project. It includes a summary of the current energy market, an analysis of current performance issues facing the parties involved, and an assessment of their respective interests and roles. In addition, current regulations, industry practices, and state data management standards will be examined.

2.1 The Energy Market

The world energy market is composed of a variety of energy sources, both renewable and non-renewable, including oil, natural gas, hydroelectric, and nuclear energy. The United States and other nations around the globe have major investments in energy and thrive on its uses. As a result, the United States created the Office of Energy Market Regulation (OEMR) within the

Federal Energy Regulatory Commission (FERC 2011). These agencies function mainly to "advise the Commission and process caseload related to the economic regulation of the electric utility, natural gas and oil industries. (p.2)" Along with this agency, many other federal agencies carry out important roles that influence the many developments within the energy market. Examples include the Department of the Interior, which "protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future (U.S. Department of the Interior, 2011)" as well as the DOE, which ensures "America's security and prosperity by addressing its energy, environmental and nuclear challenges (Department of Energy, 2011)."

Energy is currently one of the most frequently traded commodities in the world. Today, natural gas, oil, and coal supply roughly eighty five percent of America's energy (Andrews, 2010, p.2). The United States energy consumption is divided into four major sectors of the economy.

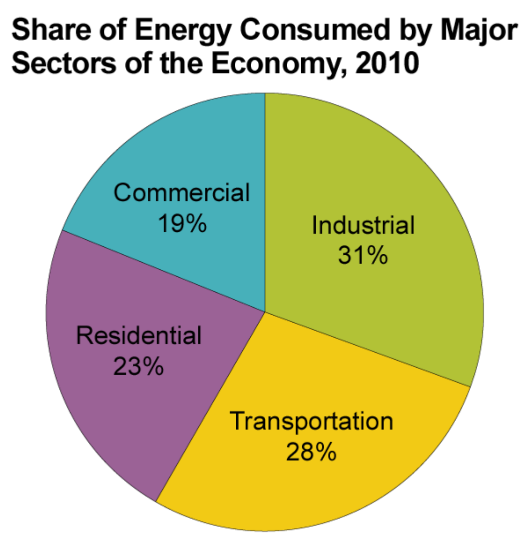


Figure 1: Share of Energy Consumed by Major Sectors of the Economy

(Energy Information Administration, 2011)

As seen in Figure 1, in 2010, nineteen percent of the energy was used commercially, thirty one percent industrially, twenty three percent residentially, and twenty eight percent was allotted to transportation. Natural gas is poised to have an increased role in all four of these sectors in the upcoming years. America's economy is directly intertwined with growth in energy production. As this trend continues, the United States will become even more reliant on the availability, production, and consumption of energy.

2.1.1 Natural Gas

Natural gas is a relatively clean burning form of energy. In comparison to using coal or oil, natural gas releases far fewer pollutants into the atmosphere. Due to this fact, natural gas is gaining more widespread use throughout the United States. Through both horizontal and vertical drilling, natural gas can be harvested from shale and other hydrocarbon-rich rock formations, depending on the location. As of 2010, the United States produced 98.2 percent of the natural gas it consumed. Currently, the largest producer of natural gas in the United States is the state of Texas. At the United States current energy consumption rate, the amount of natural gas stored in domestic rock formations is projected to be enough to supply the country for over one hundred years (Natural Gas, 2011, p.4). Currently, generation of electric power is the main use of natural gas in the United States, representing roughly thirty one percent of total gas use. Industrial uses are a close second, accounting for twenty seven percent of domestic gas use (U.S. Energy Information Administration).

Other uses of natural gas include heating and cooling of commercial and residential buildings, transportation fuel for natural gas vehicles (NGVs) and the manufacturing of products such as steel, glass, paper, clothing, and bricks. The fact that natural gas can be used in such a wide range of applications in combination with the relatively new technological advances in the shale gas extraction industry is predicted to result in an increase in shale gas production in coming years. According to the Energy Information Administration, shale gas production is predicted to increase to forty seven percent of total U.S. natural gas production by 2035 shown in Figure 2 (EIA-DOE, 2011).

U.S. Natural Gas Production (1990-2035)
(millions of cubic feet per year)

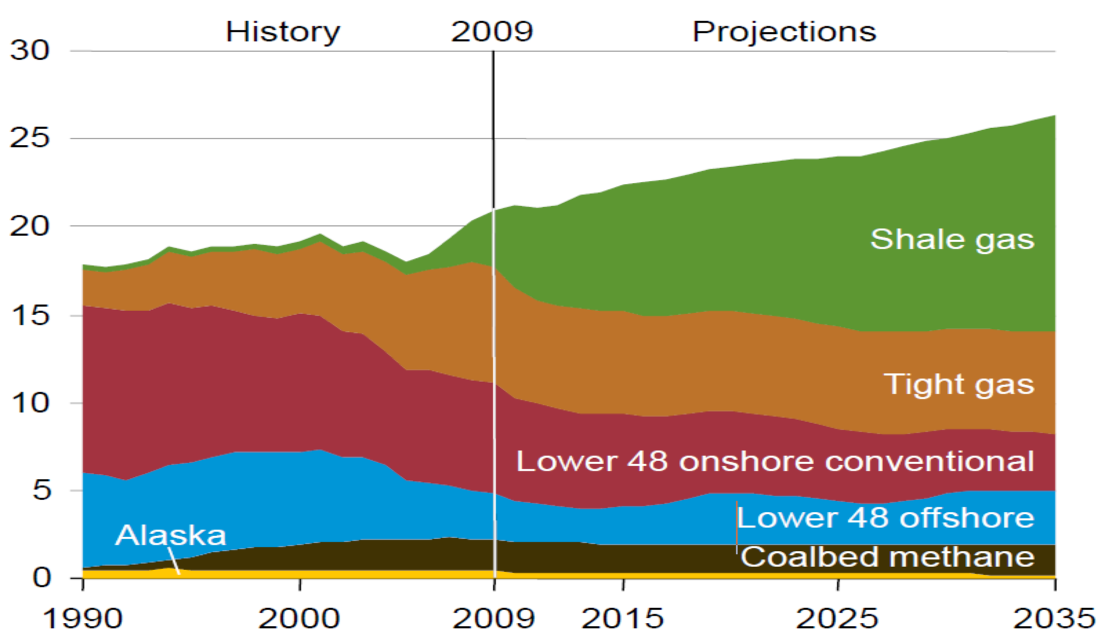


Figure 2: U.S. Natural Gas Production (1990-2035)

(EIA-DOE, 2011)

Natural gas prices in the United States are largely determined by the balance of supply and demand within North America. Increased production of shale gas, which grew from 2.7

billion cubic feet (bcf) per day in 2006 to an estimated 13.3 bcf per day in 2010, has contributed to a significant moderation in natural gas prices (Newell, 2011, 3).

2.2 History of Natural Gas

Shale is a black, hydrocarbon-rich, material formed by the deposition of clay particles that trap organic matter. These particles degrade over time and form natural gas. According to Dr. Gary Lash, a geology professor at the State University of New York at Fredonia, “A number of factors contributed to the organic nature of the Marcellus, including the very warm climate that existed during the Devonian period. You had a warm layer of water at the surface, which precluded the transport of oxygen to the ocean bottom, meaning that the organic matter at the bottom remained and was preserved. That organic matter was eventually transformed into hydrocarbons (Hayes, 2011, p. 8).” An outline of the Marcellus Shale can be seen in Figure 3.

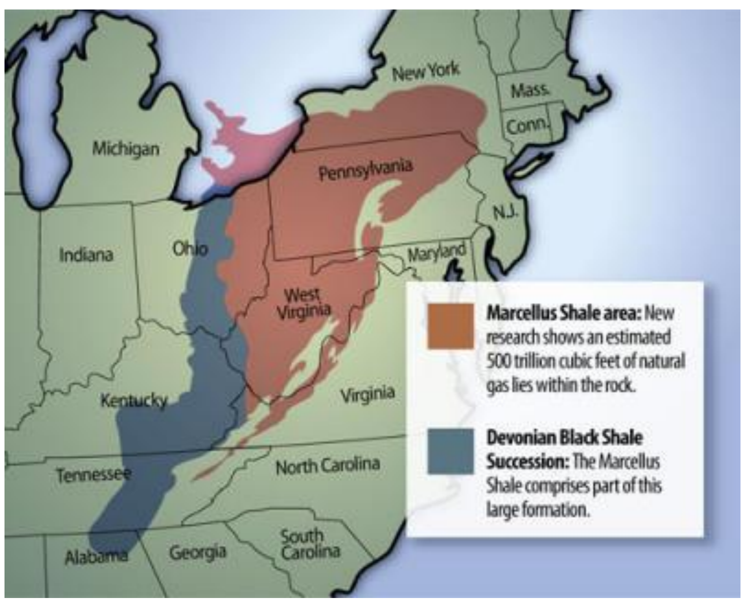


Figure 3: Marcellus Shale Region

(Perry, 2011)

Natural gas has been trapped in the relatively impermeable stone of the Marcellus Shale for millions of years. Natural gas extracted from shale has been an option as a source of energy for decades, but until recently, there were many technological and physical challenges associated with extracting significant quantities of this gas from these complex geological formations at economically recoverable rates. This valuable natural gas is stored within dense shale in reservoirs, generally 5,000 to 15,000 feet below the earth's surface. Shale formations are typically denser than concrete with low porosity and low permeability. This fact makes drilling into the rock very difficult, and therefore, very costly (Wickstrom & Perry, 2010).

While the practice of harvesting the gas stored in the Marcellus Shale play is just beginning to develop, natural gas itself has been a component of energy consumption in the United States since the nineteenth century (Wickstrom & Perry, 2010). In 1821, the Devonian Shale in New York's Appalachian region became the first commercial natural gas production site in the United States. Most of the earlier drilling focused on "shallower, high-organic zones with high frequencies of natural fractures" (p. 17). It took until the 1970's and many millions of dollars in research and development activities to more fully understand the geological nature of the shale and the chemical nature of the organic matter contained therein.

In 1981, Mitchell Energy & Development began tapping into shale that the company had previously ignored (Curtis, 2002). At founder George Mitchell's steadfast insistence, the company spent "twelve years, more than thirty experimental wells and millions of dollars" before they came up with the solution of combining hydraulic fracturing and horizontally drilled wells (p. 1921). Hydraulic fracturing consists of injecting a high-volume mixture of water and sand, along with small amounts of chemical additives, into the shale formation at a very high-pressure. This process fractures the rock and releases the gas molecules allowing their ultimate recovery at the wellhead. “From 2000 to 2008, the number of active gas wells drilled in New York State nearly doubled from 6,845 to 13,687, and over the next [few] decades an additional 80,000 wells could be drilled” (Finkel & Law, 2011, p. 784).” With the development of horizontal wells and hydraulic fracturing, the size and economic significance of the shale gas industry has greatly increased. Today, shale gas exploration is occurring in deeper formations, requiring more water and higher pressures to fracture the shale and recover the gas. In 2003, Range Resources began exploratory drilling in Pennsylvania and experimented with using techniques developed in Texas (Wickstrom & Perry, 2010, p. 18). In 2005, the company began commercially producing natural gas from its Marcellus Shale wells. Competitors took note and followed suit. The Marcellus Shale has an area of 140, 000 km^2 with an average thickness thirty meters. In some areas of northeastern Pennsylvania, the Marcellus Shale has been measured to as thick as seventy five meters (Lee, Herman, Elsworth, Kim, & Lee, A Critical Evaluation of Unconventional Gas Recovery from the Marcellus Shale, 2011). The richest amount of gas is located in north-central Pennsylvania and south-central New York. Generally, the Marcellus shale increases in depth and thickness towards the East (p. 681). This thicker shale likely contains more natural gas, but the added depth increases the costs associated with drilling.

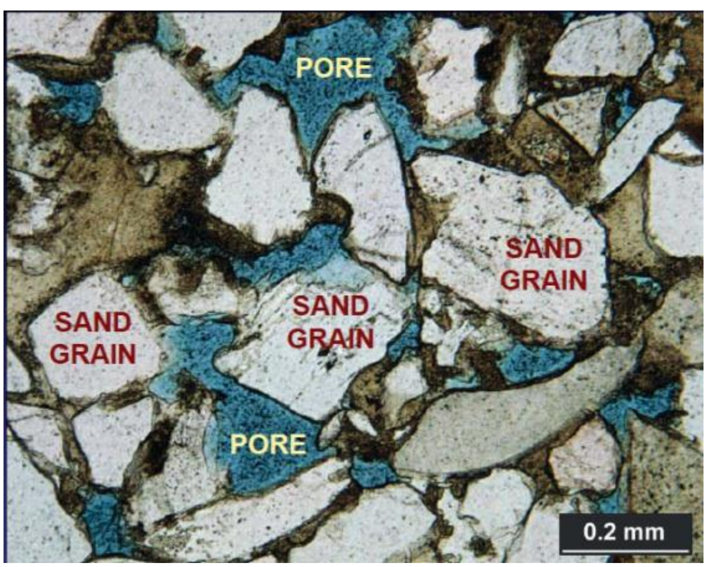


Figure 4: Pore Spaces in Shale

(Wickstrom & Perry, 2010)

The pore spaces of the shale, shown in Figure 4, where the methane is trapped, are poorly connected (p. 681). This means that drilling must be executed precisely in order to hit the areas with a high concentration of pores.

2.3 Benefits of Shale Gas in Marcellus Shale

Despite the controversy that surrounds many facets of drilling for Marcellus Shale gas, there are some clear cut benefits to the continuing development of this industry. Firstly, there is the opportunity to replace the environmentally unfriendly energy sources that are so widely consumed with a source that is potentially far cleaner. Also, shifting some of the nation’s energy consumption from foreign fossil fuels to a source produced domestically, offers some undeniable economic and energy security benefits, particularly in these volatile times where energy producing nations in the Middle East are experiencing dramatic changes and growth of the world economy continues to be at risk. The struggling American economy could benefit from the substantial boost in economic activity that widespread shale gas development could yield. Developing the shale gas industry could bring much needed jobs and industry to some of the most rural communities along the east coast and elsewhere. Thus, carefully and safely harvesting the Marcellus Shale gas could have some substantial environmental, political, and economic benefits.

The irony of the environmental disputes that currently surround the drilling in the Marcellus Shale lies in the fact that natural gas is, in many ways, more environmentally friendly than some of the other widely used energy sources. In comparison to burning coal, for instance, natural gas produces far fewer greenhouse gasses. According to a recent study conducted by Carnegie Mellon University, burning Marcellus Shale gas rather than coal could reduce our greenhouse gas production by as much as twenty to fifty percent (Marcellus Shale gas cleaner than coal, CMU study says, 2011, p.1). Burning natural gas produces substantially less carbon dioxide than both oil and coal (Natural gas and the environment, 2011, p.3). Unlike energy obtained from various sources abroad, energy produced in the United States can be monitored by this country to ensure appropriate environmental standards. The potential environmental benefits of natural gas do not in any way discredit current environmental concerns associated with the drilling process. Instead, they suggest that, if drilling is carefully performed and regulated, shale gas could be a viable and cleaner burning source of alternative energy.

Shifting from internationally supplied petroleum products to natural gas harvested domestically could positively impact the United States and the world politically. In 2010, the United States consumed over 19.1 million barrels per day in petroleum products. According to the EIA, approximately half of U.S petroleum imports come from the Western Hemisphere. An additional eighteen percent comes from nations in the Persian Gulf (Annual energy outlook, 2010, p.4). In his book, *Hot, Flat, and Crowded*, Thomas L. Friedman suggests that the United States' dependence on foreign oil not only hurts the United States but also helps support some of the world's worst dictators in terms of human rights. On a more fundamental level, instabilities in the regions that produce imported oil lend themselves to instabilities in American energy prices. Transitioning some of the United States energy consumption from foreign petroleum based products to domestically produced natural gas could help address some of the complicated political issues created by foreign energy dependence.

There is evidence to suggest that the industry developed by drilling for Marcellus Shale gas could provide much needed economic stimulation. An industry funded study, co–authored by economist Timothy Considine along with Robert Watson, Rebecca Entler, and Jeffery Sparks, argued that the economic benefits of Marcellus drilling would be far reaching. The study concluded that there was a 4.8 billion dollar increase in gross regional product for West Virginia and Pennsylvania due to Marcellus drilling in 2009. These two states also saw an additional 57,357 jobs created by this industry (An emerging giant: Prospects and economic impacts of developing the Marcellus Shale natural gas play, 2008, p. 2). There is no doubt that continuing to develop this industry would lead to more economic growth.

2.4 Life Cycle of a Well

Establishing a commercially producing shale gas well is a multifaceted endeavor and can often take more than a year. The process includes identifying a drilling site, designing a well based upon the geography and geology of the specific location, constructing the well, testing the well, and eventually decommissioning the well after production has ceased. All of these tasks are time consuming and require efficient planning and execution, but the final product can often be a very profitable investment.

2.4.1 Site Investigation

Extracting natural gas from the Marcellus Shale begins with selecting the most practical and cost effective site available. Often, this process includes leasing the gas and oil rights from private land owners. Other factors that influence this decision include laws and regulations, proximity to infrastructure such as roads and fueling stations, and most importantly the likelihood that the site will yield a large quantity of hydrocarbons at minimal cost (EPA, 2011, p. 10).

The likelihood of the well site producing a large amount of gas is determined using a number of methods. One of the first methods employed is aerial surveillance photography to verify if the geography is suitable for drilling. An understanding of the subsurface geology is also important for the selection of a drilling site. Assessment of the geological formations includes seismic and magnetic analyses, which provide the drilling companies with more detailed information about the rock formations below the surface (E&P Forum, 1997, p. 4). Seismic analysis "is often the first field activity taken (E&P Forum, 1997, p. 4)" when investigating a possible well site. The seismic testing equipment is shown below in Figure 5.

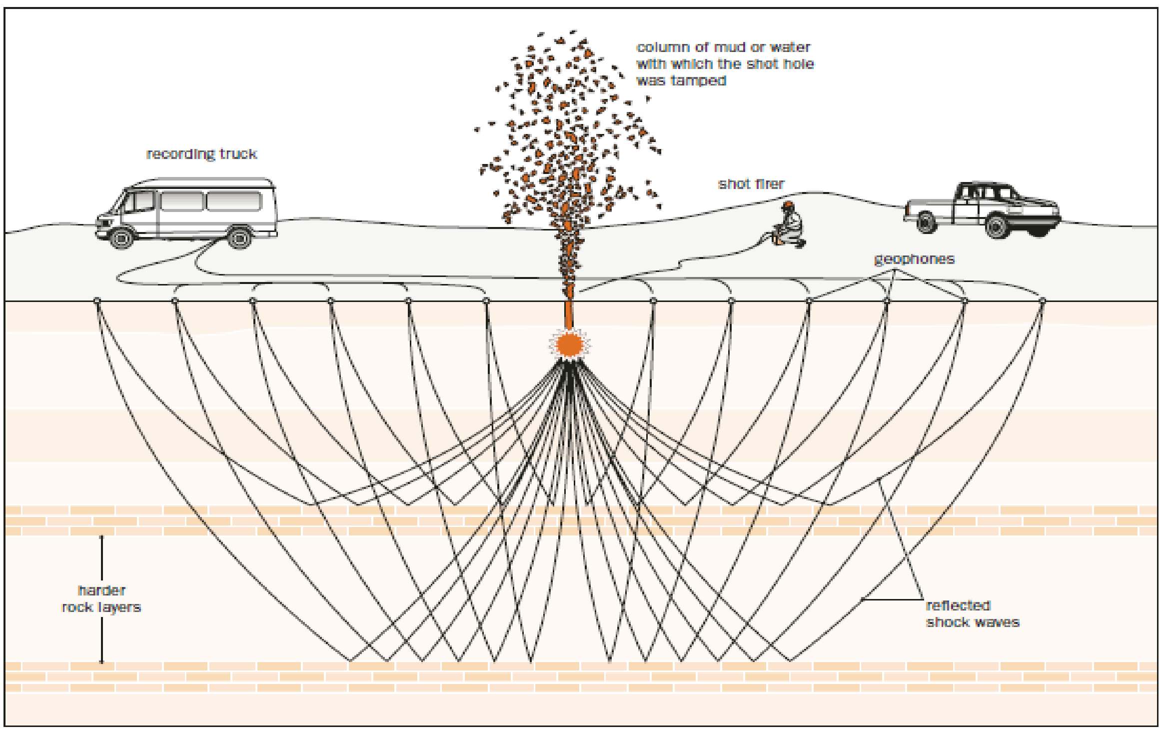


Figure 5: Seismic Testing

(E&P Forum, 1997)

The analysis begins when an energy source, such as a small explosion, is applied to the ground and sends out seismic waves. As the waves travel through the ground, some are reflected off of certain rock formations and are directed back to the surface where sensitive receivers called geophones can interpret the signals. These signals are amplified, filtered, digitalized, and recorded in a mobile laboratory for interpretation (E&P Forum, 1997, p. 4). The magnetic analysis method consists of applying a magnetic field to the formation and measuring variation in the field. Variation in this field can be used to identify certain rock formations based on the differences in magnetic character between the various types of rock. Using these methods, drilling companies look to estimate the depth and thickness of target shale formations.

Once a promising site has been identified, the thickness and internal pressure of the target formation must be determined. This information is gathered by the drilling and testing of exploratory wells. The exploratory wells are located on a drilling pad; the characteristics of which depend upon the terrain and the drilling equipment being used. A rig is assembled on the drilling pad and is composed of “a derrick, drilling mud handling equipment, power generators, cementing equipment and fuel tanks for fuel and water (E&P Forum, 1997, p. 6).” The derrick can be seen in Figure 6.

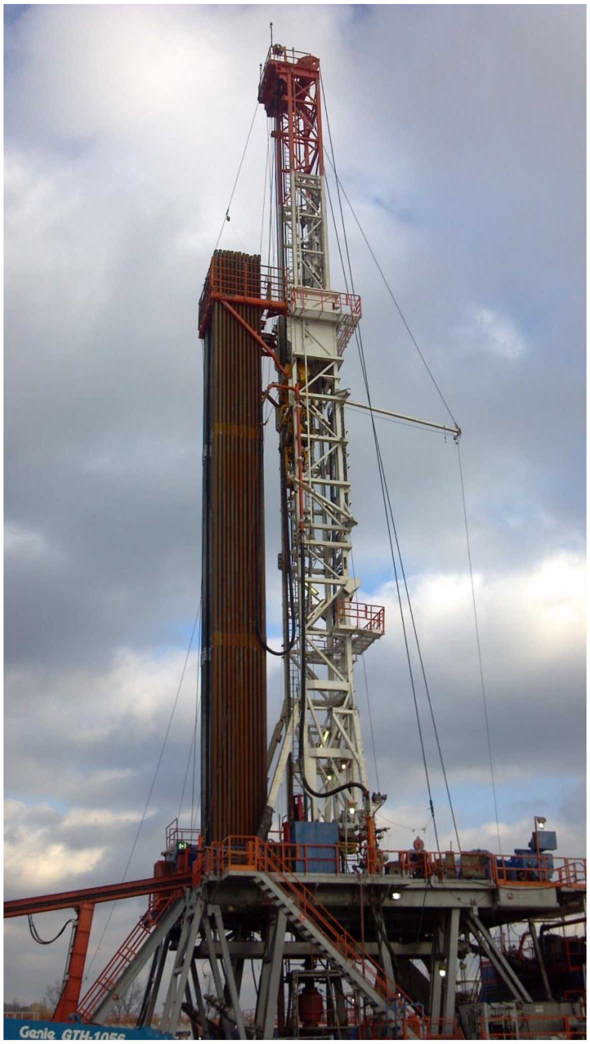


Figure 6: Drilling Rig

(Photographer: Kassandra Ruggles)

This equipment is then used to drill into the ground until the hydrocarbon formation is reached. Once the target formation is penetrated, testing can begin in order to determine if the well site is appropriate for further development. Initial well tests determine the flow rate of the gas as well as the pressure contained in the formation. If exploratory drilling demonstrates that commercial quantities of hydrocarbons have been found, a wellhead valve is installed (E&P Forum, 1997, p. 7). If the site is deemed non-profitable, “the site is decommissioned to a safe and stable condition and restored to its original state or an agreed after use. Open rock formations are sealed with cement plugs to prevent upward migration of wellbore fluids (p. 7)."

2.4.2 Well Construction

The American Petroleum Institute states that "the goal of the well design is to ensure the environmentally sound, safe production of hydrocarbons by containing them inside the well, protecting ground water resources, isolating the production formations from other formations, and by proper execution of the hydraulic fractures and other stimulation operations (EPA, 2011, p. 13)." The well is composed of several layers of steel casing surrounded by cement in order to isolate the production zone (EPA, 2011, p. 13). Figure 7 shows the layers of cement used to stabilize and seal the steel casings.

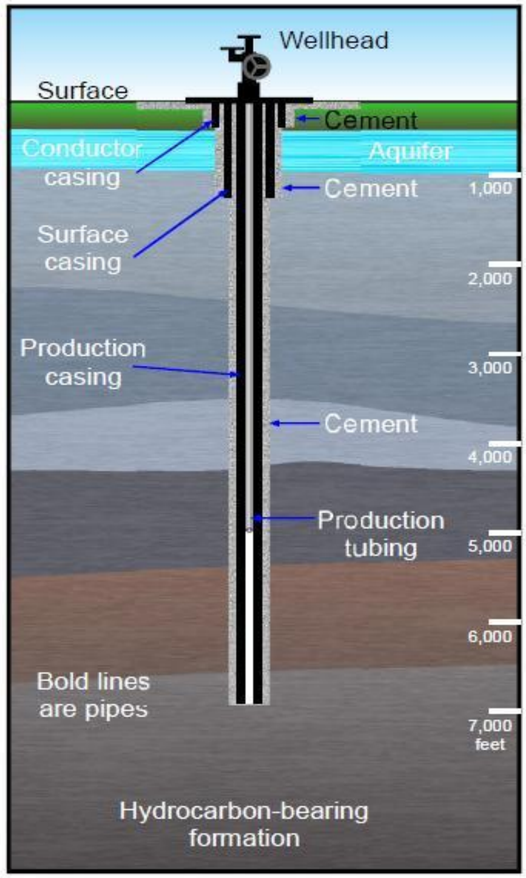


Figure 7: Well Casing Construction

(EPA, 2011)

2.4.3 Types of Wells

There are two main types of wells used to extract natural gas from subsurface rock formations. Vertical wells drill straight down into the target formation with the fractures extending horizontally from the wellbore. Horizontally drilled wells differ in the fact that the wellbore is turned prior to reaching the target formation. This allows the wellbore to enter the production zone at an angle and extend laterally through the formation for thousands of feet. The decision to drill either horizontally or vertically is based upon the geology of the site. There are pros and cons to each process. For example in the Marcellus Shale, "a vertical well may be exposed to as little as fifty feet of the gas shale, while a horizontal well may be developed with a lateral wellbore extending 2,000 to 6,000 feet within the fifty to three hundred feet thick organic-rich shale (Srivastava, 2010)." Although horizontally drilled wells are generally more productive, they also have some downsides associated with their construction. One of the negative aspects of horizontal drilling is the large volume of water required to fracture the shale along the long lateral portion of the well. "The amount of water typically required for hydraulic fracturing ranges from approximately one million gallons for a vertical well to approximately five million gallons for a horizontal well (Srivastava, 2010)." Vertical drilling allows more cost effective access to shallower developments, which are close to underground water sources (EPA, 2011).

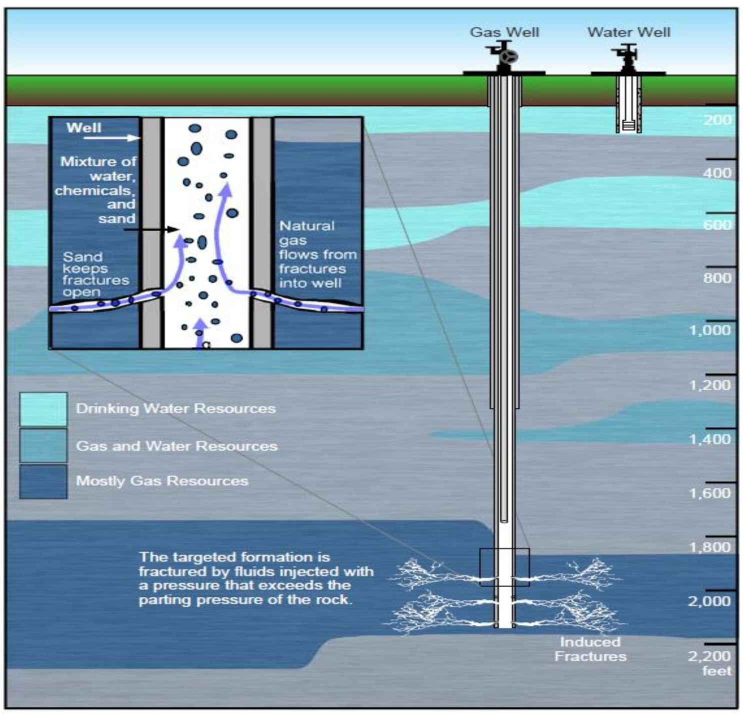


Figure 8: Vertical Well Construction

(EPA, 2011)

Figure 8 depicts a vertical well which shows the depth of the formation with relation to the drinking water sources. It also shows the level of protection that a gas well must have in comparison to a drinking water well.

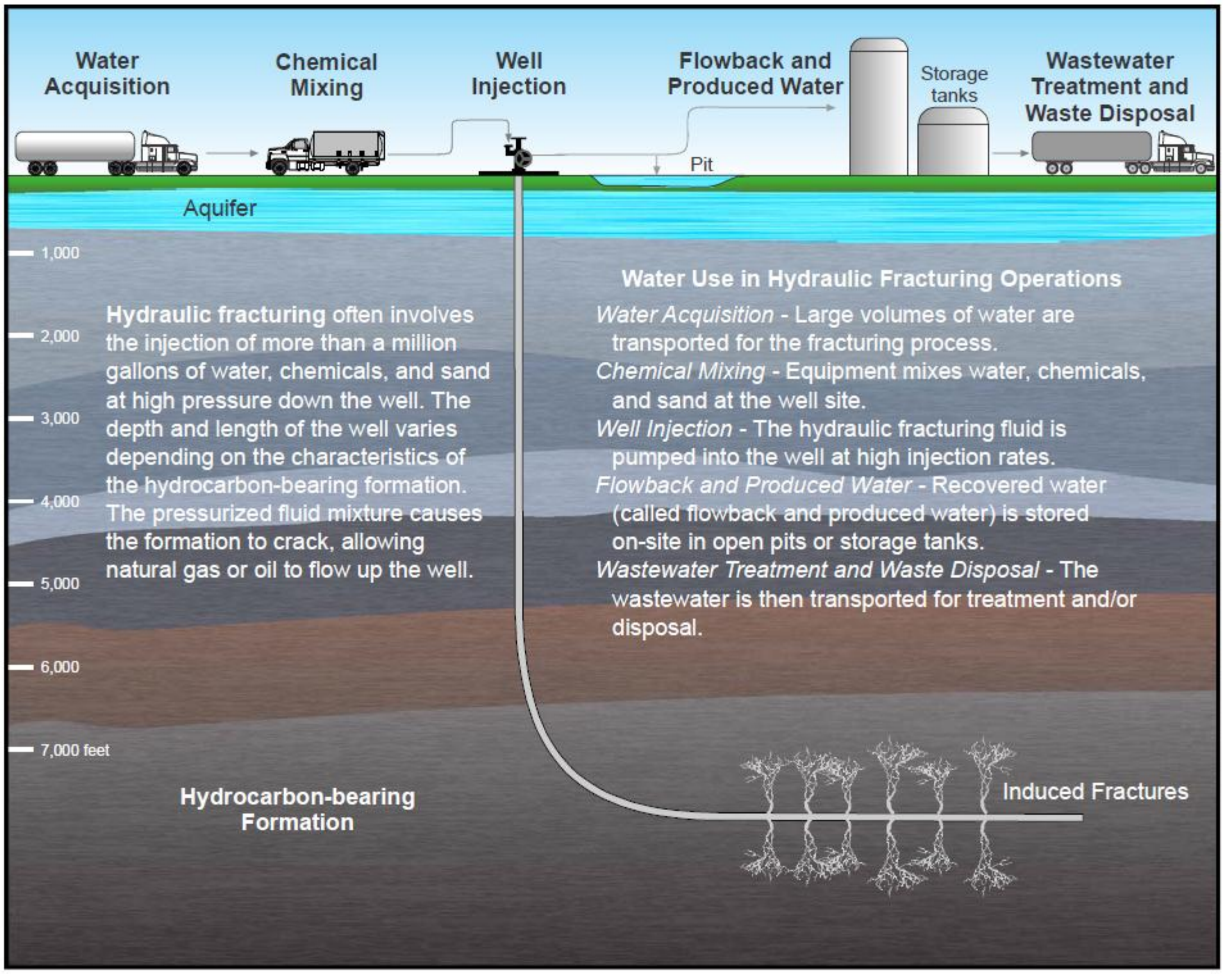


Figure 9: Horizontal Well Construction

(EPA, 2011)

Figure 9 shows how a horizontally drilled well is composed of both a vertical and a horizontal section. Before the turning of the drill bit, the construction process is the same as that of a vertical well. As the wellbore approaches the target formation, the angle of drilling is changed and construction of the lateral portion of the well begins. The horizontal section of the wellbore extends laterally through the shale formation. The length of the horizontal portion depends upon the geology of the formation as well as other factors such as the limits of the operators oil and gas rights. (EPA, 2011, p. 13). Horizontal drilling is seen as more favorable to the drilling companies because it provides a larger volume of gas production, which leads to greater economic benefits. To the land owners, the process is also more favorable because it has the "advantage of limiting environmental disturbances on the surface because fewer wells are needed to access the natural gas resources in a particular area (EPA, 2011, p. 13)." Figure 10 illustrates the differences in production rates for horizontal and vertical wells. Horizontal wells produce more gas in a shorter amount of time than vertical wells.

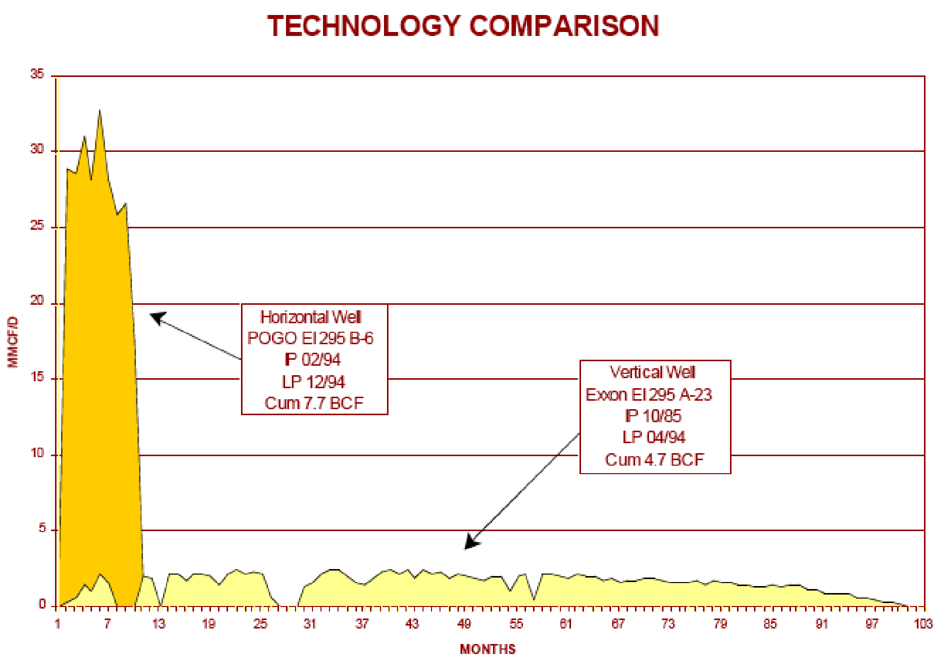


Figure 10: Horizontal vs. Vertical Production Rates

(Summers, 2009)

The number of wells required to exploit the hydrocarbon reservoirs varies with the size and geology of the reservoir (E&P Forum, 1997, p. 8). Larger formations such as the Marcellus require hundreds, even thousands, of wells. This is why multilateral drilling has become a more popular practice. "In multilateral drilling, two or more horizontal production holes are drilled from a single surface location to create an arrangement resembling an upside-down tree, with the vertical portion of the well as the 'trunk' and multiple 'branches' extending out from it in different directions and at different paths (EPA, 2011, p. 13)."

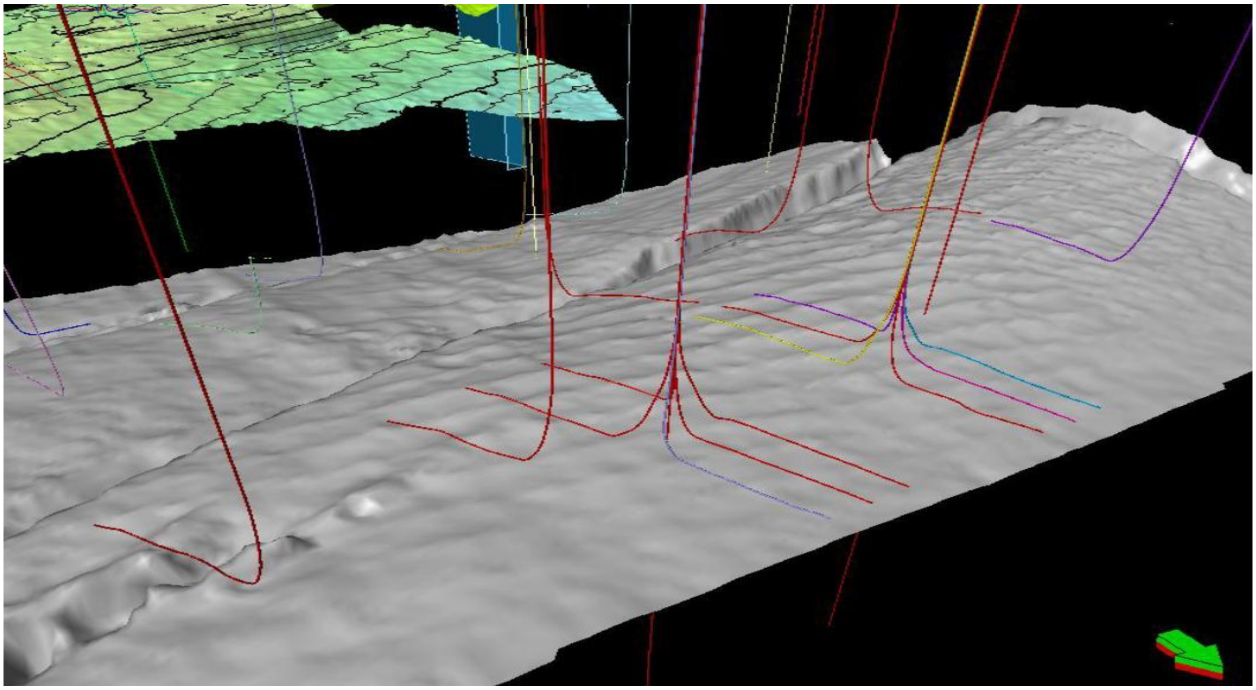


Figure 11: Multilateral Well Arrangement

(Shell Appalachia, 2011)

Figure 11 shows a subsurface view of a multilateral well arrangement. Multilateral well pads allow increased access to the target formation from a single drilling location. This construction decreases the impact on the surface environment.

2.4.4 Drilling

Drilling a bore hole typically takes one to two months, although this depends on the geology of the drilling site (E&P Forum, 1997, p. 7). The drill bit, drill collars, and a drill pipe make up the drilling string used to drill the well (EPA, 2011, p. 13). The drilling string is a hollow assembly which is lowered into the ground and allows the circulation of drilling fluid to the drill bit. The drill bit is a vital component located at the bottom of the drill string. The horizontal portion of a well is drilled using a drilling motor assembly with a slight one to two degree bend as seen in Figure 12.

Figure 12: Horizontal Drilling Motor Assembly

(Photographer: Sheila Werth)

The drill bit "is responsible for actually making contact with the subsurface layers, and drilling through them (Rotary Drilling, 2011)." Drill bit design is dependent upon the type of subsurface formation that is being drilled through, as well as the thickness and density of the formation. There are five main design conditions to consider when choosing drill bits for a specific location: "the underground formations expected to be encountered, the type of drilling used, whether or not directional drilling is needed, the expected temperatures underneath the earth, and whether or not cores are required (Rotary Drilling, 2011)."

Once the criteria for drilling have been established, there are multiple types of bits to choose from. Steel tooth rotary bits are the most basic type of drill bit used today and consist of multiple rotating drilling surfaces. Hammer bits are blunt circular bits which are used to pulverize the rock. These bits work similarly to a jack hammer and can be seen in Figure 13.

Figure 13: Hammer Bit

(Photographer: Griffin Walker)

Insert bits are steel tooth bits with tungsten carbide inserts. These bits are often used to drill the horizontal portion of the well including through the shale formation. An example of an insert bit can be seen in Figure 14.

Figure 14: Tungsten Carbide Insert Bit

(Photographer: Griffin Walker)

Polycrystalline diamond compact bits are insert bits with polycrystalline diamond attached to the carbide inserts. Diamond bits use industrial diamonds implanted in them to drill through extremely hard rock formations. Diamond bits are forty to fifty times harder than traditional steel bits, and can thus be used to drill through extremely dense rock without dulling overly quickly (Rotary Drilling, 2011).

Typically, a drilling engineer will employ multiple bits depending on what types of rock are being drilled into. This practice maximizes the effectiveness of each bit while reducing cost, as different bits can vary greatly in price (Rotary Drilling, 2011). Circulation of drilling fluid, often referred to as mud, is required to keep the drill bit cool as well as to flush away the pieces of rock. As the drilling progresses, the constant circulation of this fluid also helps to control the pressure inside the wellbore (EPA, 2011, p. 14). Drilling fluid is normally composed of a mixture of water, barite, clay, and chemical additives. Once the final depth and extent of the wellbore are achieved, the drill bit and fluid are removed and must be either chemically treated to remove toxins or properly disposed of (EPA, 2011, p. 14).

2.4.5 Casing

The steel pipes that are used to isolate the well from the outside rock formation and water sources are referred to as the well casing. The casing must being able to withstand the “various compressive, tensional, and bending forces that are exerted… as well as the collapse and burst pressures that it might be subjected to during different phases of the well’s life (API Energy, 2009, p. 4).” It is the responsibility of the drilling company or the subcontractor’s drilling engineer to design the casing (p. 4). Both ends of the casing are threaded and screwed together making a “string” of casing sections. The joints between casing sections account for only three percent of total casing length, but ninety percent of casing failures occur at these connections (Devon Energy Corporation).

Each wellbore has four main casing components: conductor, surface, intermediate and production casings (API Energy, 2009, p. 11). Figure 15 shows the arrangement of casings for both a horizontal and vertical wells.

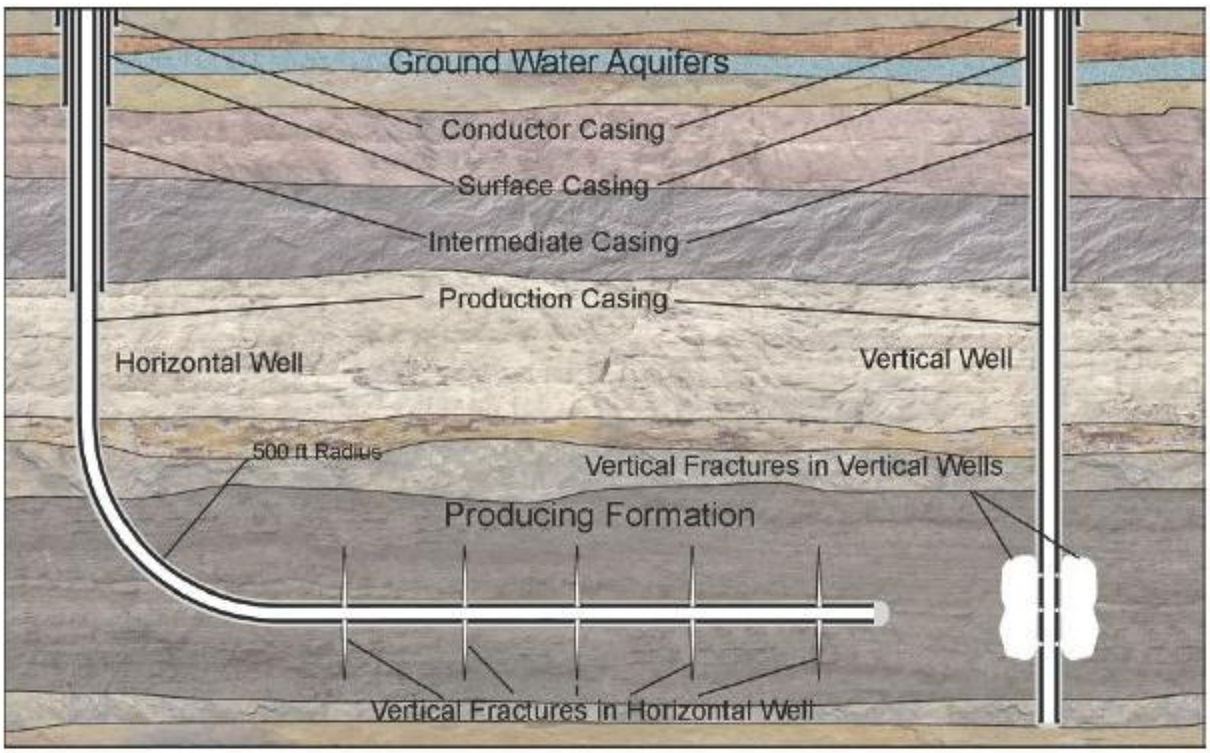


Figure 15: Horizontal and Vertical Well Casing

(API Energy, 2009)

The first casing inserted is the conductor casing. The conductor casing has the largest diameter of the four casings and once driven into place, it serves as structural piling (API Energy, 2009, p. 4). This keeps the unconsolidated sediment in place while drilling occurs. After the conductor casing is inserted, it is cemented in place in order to provide maximum stability and isolate the wellbore from any shallow groundwater. The depth of the conductor casing is influenced by the location of nearby wells. Next, the surface casing hole is drilled, the surface casing is inserted, and cemented in place. The main purpose of this casing is to isolate the wellbore and protect underground aquifers (API Energy, 2009, p. 11). Two sections of surface casing can be seen in Figure 16.

Figure 16: Twenty Inch Surface Casing

(Photographer: Sheila Werth)

State regulations dictate the depth of the casing. According to Pennsylvania code 78.83 “the operator shall drill approximately fifty feet below the deepest fresh groundwater or at least fifty feet into consolidated rock, whichever is deeper, and immediately set and permanently cement a string of surface casing to that depth (State of Pennsylvania, 2011).” In comparison, West Virginia code 35-4-11.3 states, “The fresh water protective casing…shall extend at least thirty feet below the deepest fresh water horizon…and shall have cement circulated in the annular space outside the casing (State of West Virginia, 2010).” The American Petroleum Institute (API) states, “at a minimum, it is recommended that the surface casing be set at least one hundred feet below the deepest USDW [Underground Source of Drinking Water] encountered while drilling the well (API Energy, 2009)."

Current API standards suggest that the casing should be pressure tested; this determines "if the casing integrity is adequate to meet the well design and construction objectives (API Energy, 2009, p. 11)." After the surface casing has been cemented in position, intermediate drilling takes place. Intermediate drilling extends the wellbore towards the point where directional drilling begins. After this section of drilling is completed, the intermediate string of casing is inserted and cemented in place. This casing is used "to isolate subsurface formations that may cause borehole instability and to provide protection from abnormally pressured subsurface formations (API Energy, 2009, p. 12)." It is not always required to cement the intermediate casing back to the surface. This is due to the fact that the surface casing and cement are meant to fully isolate the underground aquifer (API Energy, 2009, p. 12). API suggests that, "At minimum the cement should extend above any exposed USDW or any hydrocarbon bearing zone (API Energy, 2009, p. 12)." Following the cementing of the intermediate casing, the final hole is drilled for the placement of the production casing. This casing runs the entire depth of the wellbore "to provide the zonal isolation between the producing zone and all other subsurface formations. …It also contains the down hole production equipment (API Energy, 2009, p. 12)." Production casing is typically five to six inches in diameter, as shown below in Figure 17.

Figure 17: Production Casing

(Photographer: Kassandra Ruggles)

Usually, the production casing is not fully cemented, meaning that the cement does not return to the surface. It is suggested by the API that "the tail cement should be brought at least 500ft above the highest formation where hydraulic fracturing will be performed (API Energy, 2009, p. 12)."

2.4.6 Cementing

Proper cement and cementing practices are an integral part of ensuring successful well integrity (API Energy, 2009, p. 7). The API states that, "complete displacement of drilling fluid by cement and good bonding of the cement interfaces between the drilled hole and the casing immediately above the hydrocarbon formation and key parts of well integrity and seal integrity (API Energy, 2009, p. 7)." The cement is meant to completely isolate the wellbore from the surrounding geological formations with the absence of gaps and voids. In order to achieve this total isolation, the proper type of cement must be used. Pennsylvania code 78.75a states that, "the operator shall use cement that meets or exceeds the ASTM International C 150, Type I, II or

III Standard or API Specification 10 (State of Pennsylvania, 2011).” In comparison, West Virginia code 35-4-11.5 states that the “cement used to fill the annular space around the casing…shall be American Petroleum Institute Class A Ordinary Portland cement with no greater than three percent calcium chloride and no other additives (State of West Virginia, 2010).” These types of cement are best suited for use in the varying temperatures and subsurface conditions throughout the wellbore. The table below summarizes the specified depth and types of cements required by Pennsylvania, West Virginia and the API.

Standard	Depth	Cement Specifications
API	100 feet past USDW	
Pennsylvania	50 feet past deepest freshwater source	ASTM International C 150, Type I, II or III Standard or API Specification 10
West Virginia	30 feet past deepest freshwater source	American Petroleum Institute Class A Ordinary Portland

Table 1: API, Pennsylvania, and West Virginia Cement Depth and Specifications

After each section of casing is inserted to the wellbore it must be cemented in place. This is accomplished by pumping liquid cement, also known as slurry, down the inside of the each casing, out the bottom, and back up the outside of the casing as seen in Figure 18.

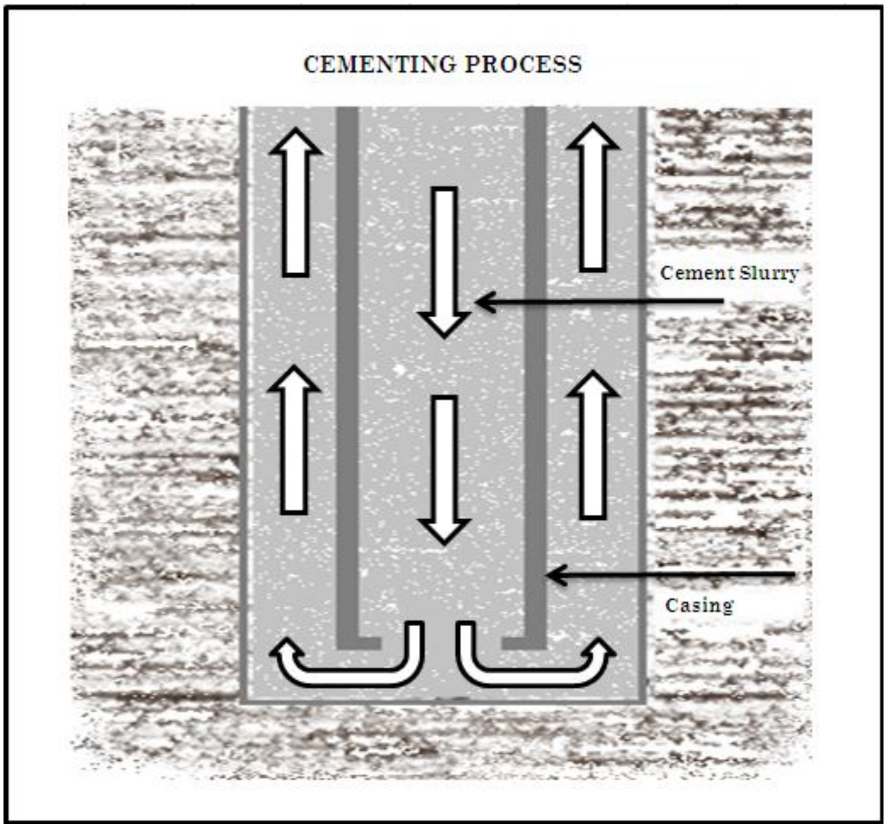


Figure 18: Cementing Process

(Artist: Sheila Werth)

The cement is mixed on site in large trucks and pumped to the rig and into the casing. Figure 19 shows this process.

Figure 19: Cementing

(Photographer: Kassandra Ruggles)

Wiper plugs are components used to separate the drilling fluid from the cement slurry as shown in Figure 20. They are used to minimize the mixing of cement with the drilling fluid as well as ensure that no cement remains on the inside of the casing. Centralizers are used to center the casing to ensure that it will be completely surrounded by cement allowing for complete isolation (API Energy, 2009, p. 8). The number of centralizers is specified by state regulations (EPA, 2011, p. 14). Once the cement is poured, an eight hour wait time must be observed before further activities to ensure that the cement is fully solidified.

Below, Figure 20 shows the cementing process:

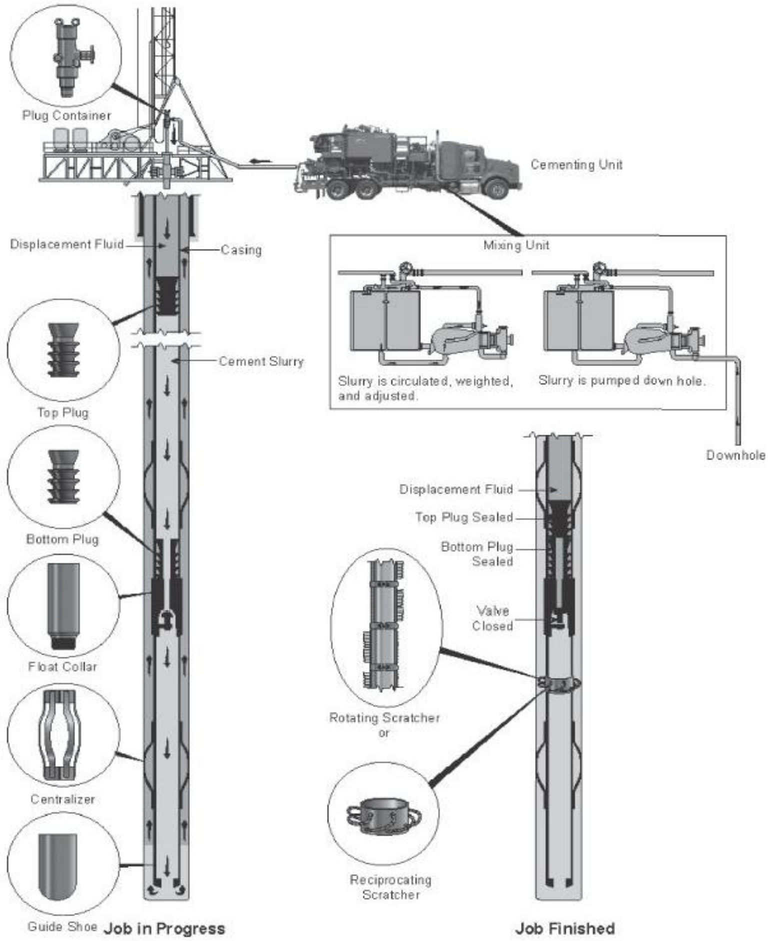


Figure 20: Cementing Process

(API Energy, 2009)

2.4.7 Well Testing

One of the most important parts of operating a safe and secure extraction site is testing the structural integrity of the well components to make sure they are properly constructed. Without these tests, the operator cannot be sure that the well will function properly. Integrity tests can either be conducted mechanically or with hydraulic pressure tests. These tests are used to uncover specific information about the well construction and are often referred to as well logs. Open-hole logging is used for “locating and evaluating the hydrocarbon producing formations” before the casings are installed (API Energy, 2009, p. 9). Testing instruments are lowered into the drilled hole on an electrical cable. A common logging tool used is called a “caliper” (API

Energy, 2009, p. 9). This is used for “a physical measurement of the diameter of the wellbore. A caliper log run through a wellbore is used to calculate the hole size and volume of the wellbore, and therefore provides critical data that is used in the design of the cement job (API Energy, 2009, p. 9).” Cased hole logging occurs after the casings have been cemented in place. A cement bond log (CBL) “measures the presence of cement and the quality of the cement bond or seal between the casing and the formation (API Energy, 2009, p. 9).” A CBL is an acoustic device that functions by sending a “sound or vibration signal, and then recording the amplitude of the arrival signal. Casing that has no cement surrounding it (i.e. free pipe) will have large amplitude acoustic signal because the energy remains in the pipe. On the other hand, casing that has a good cement sheath that fills the annular space between the casing and the formation will have a much smaller amplitude signal since the casing is ‘acoustically coupled’ with the cement and the formation which causes the acoustic energy to be absorbed (API Energy, 2009, p. 9).” The bonds between the cement and both the well casing and surrounding rock formations are a fundamental part of ensuring that the wellbore is properly isolated. Therefore, this test is crucial in determining if the cement job is adequate and follows regulation.

2.4.8 Perforating

In order to extract the natural gas stored in shale formations, a pathway for the gas to travel from the rock into the production casing must be created. The first part of this process is commonly referred to as perforating. The most common method of perforating uses “specialized shaped explosive charges” to create holes in the casing, the surrounding cement, and the shale formation (API Energy, 2009, p. 14). The perforations created after the detonation of these charges allow the pressurized hydraulic fluid to enter and fracture the formation. Figure 21 below depicts the perforation process. The hole is made when “a jet of very hot, high pressure gas vaporizes the steel pipe, cement, and formation in its path (API Energy, 2009, p. 14).”

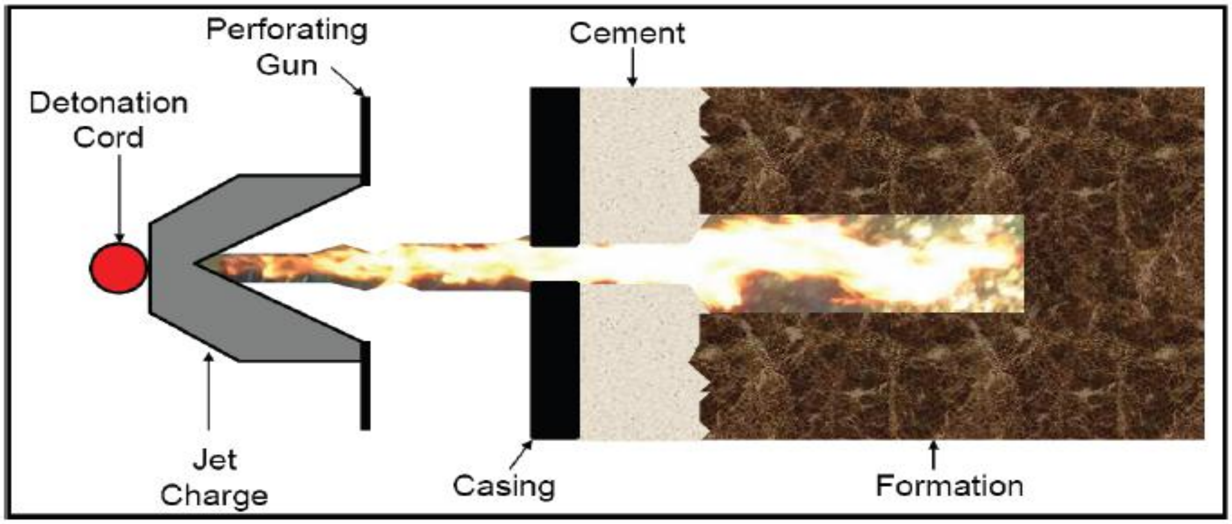


Figure 21: Production Casing Perforation

(API Energy, 2009)

As a result, an isolated tunnel is created in the formation and connects the target hydrocarbon zone with the production casing (API Energy, 2009, p. 14). Figure 22 depicts the tunnel created by the perforating process.

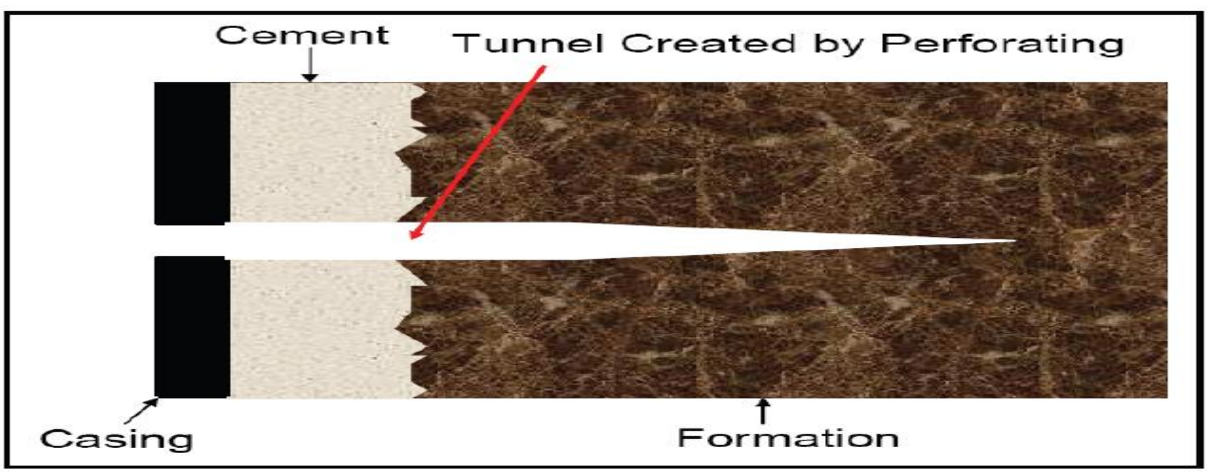


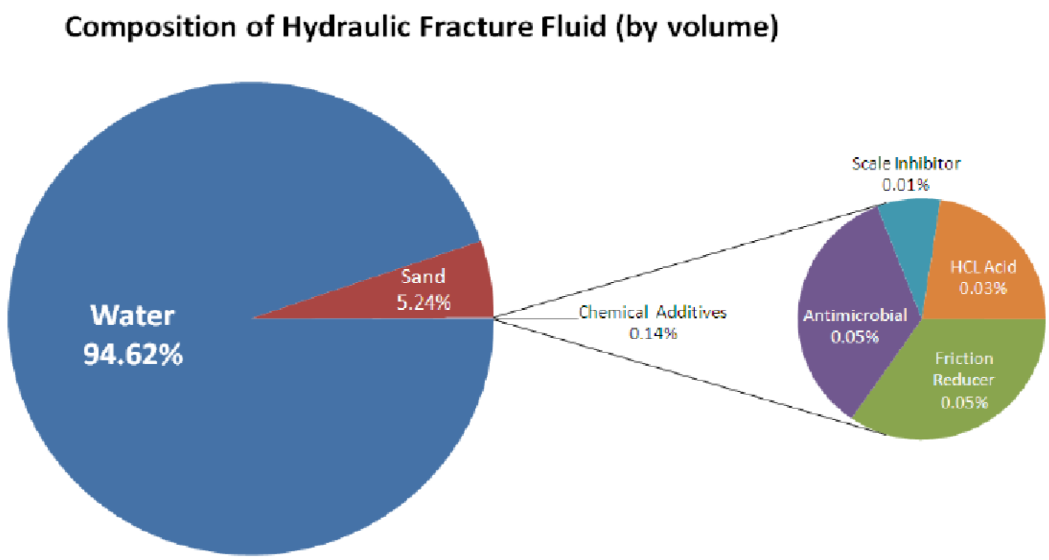
Figure 22: Production Casing After Perforation

(API Energy, 2009)

2.4.9 Fracturing

Typically, pore spaces in shale formations, even after perforation, are not large enough for small molecules like methane to flow out at a rate that would make production economical (Harper, p. 11). Therefore, hydraulic fracturing is utilized to "allow gas to travel more readily from the pores to the wellbore (Harper, p. 10)." The process of hydraulic fracturing consists of pumping large volumes of hydraulic fluid down the production casing, through the perforations, and into the target formations at very high pressures. This process causes cracks to form in the rock formation and allows the trapped gas to escape.

Fracturing fluid is composed of 99.86% water and proppants. The proppant is a solid material, usually sand, that "is used to keep the fractures open after the pressure is reduced in the well (EPA, 2011, p. 15)." The remaining 0.14% is composed of chemicals, which serve specific functions such as anticorrosives and antimicrobials (Range Resources, 2010, p. 1). Figure 23 depicts the fracturing fluid composition.



(Range Resources, 2010, p. 2)

Figure 23: Composition of Fracturing Fluid

Very large quantities of water are required to fracture a horizontally drilled well; a typical Marcellus well requires approximately 3,800,000 gallons (EPA, 2011, p. 22). The water required can be acquired from either ground or surface water depending on the site (EPA, 2011, p. 23). This water can is stored in large impoundments, as seen in Figure 24, or in steel tanks located at the well site (EPA, 2011, p. 23).

Figure 24: Water Impoundment

(NETL, 2011)

Government officials and landowners in the Marcellus Shale area are concerned with the large amount of water required for the fracturing process. This concern is due to the fact that the water is highly contaminated after being used to fracture a well. The water not only contains the chemical additives used in the fracturing process, but also a high level of dissolved salts and other contaminants from the subsurface rock formations. This concern can partially be remedied by recycling the flowback water (EPA, 2011, p. 23). However, there are concerns related to the total dissolved solids (TDS) in the water that is returned to the surface. Flowback with a high TDS concentration requires dilution with additional water and further chemical treatment in order to be reused as a new fracturing fluid (EPA, 2011, p. 23). Approximately twenty five to seventy five percent of the fluid injected can be recovered, depending on the underground conditions (EPA, 2011, p. 23). The chemicals added to the water often include a gelling agent, which reduces the friction between the fluid and the pipe (Range Resources, 2010, p. 2).

Antimicrobials are also added to "eliminate bacteria in the water that produce corrosive byproducts (Range Resources, 2010, p. 2)." There is also public concern regarding the toxicity of the chemicals involved. Based on this concern, the U.S. House of Representatives Committee on Energy and Commerce sponsored an investigation into the practices of hydraulic fracturing. Through this study, it was discovered that fracturing fluid often included "twenty nine chemicals that are: (1) known or possible human carcinogens, (2) regulated under the Safe Drinking Water Act for their risk to human health, or (3) listed as hazardous air pollutants under the Clean Air Act (EPA, 2011, p. 31)." Although these chemicals are usually injected into the target formation more than a mile below the surface, concern remains about the possible health risks associated with their use.

The fluid is pumped into the production casing at a very high pressure. It comes in contact with the formation through the perforations at the bottom of the casing. The high pressure causes the fluid to fracture the rock (API Energy, 2009, p. 15). The pressure of the fluid is high enough to propagate fractures in the otherwise impermeable rock. These fractures grow as the pressure is increased, allowing access to more surface area of the formation (API Energy, 2009, p. 15). "The fracture initiation pressure will depend on the depth and the mechanical properties of the formation (EPA, 2011, p. 34)." The fractures will develop naturally in a path of least resistance.

In a horizontal well, fracturing can occur in single or multiple stages, depending on the length of the lateral portion of the well (EPA, 2011, p. 34). "The rate at which fluid is pumped must be fast enough that the pressure necessary to propagate the fracture is maintained (API Energy, 2009, p. 15)." While the fracturing process is underway, it is important to monitor the various pressures contained within the well. This will ensure that the pressure needed for fracture propagation is maintained. The API was quoted in the EPA's Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources saying that, "monitoring the surface injection pressure is particularly important for two reasons: (1) it ensures that the pressure exerted on equipment does not exceed the tolerance of the weakest components and (2) unexpected or unusual pressure changes may be indicative of a problem that requires prompt attention (EPA, 2011, p. 34)." After the formation has been fractured, the pressure is reduced and the fluid returns to the surface. The proppant remains in the formation and helps to keep the fractures open. This allows the natural gas to escape from the small pore spaces and flow up the wellbore.

2.4.10 Well Production and Closure

The amount of natural gas produced from a well varies with the geology and the techniques used. For example, the New York State Revised Draft Supplemental Generic Environmental Impact Statement "estimates that a typical well will initially produce 2.8 million cubic feet per day (mmcf/d); the production rate will decrease to 550 thousand cubic feet per day (mcf/d) after 5 years and 225 mcf/d after ten years, after which it will drop approximately 3 percent a year (EPA, 2011, p. 16)." Once a well stops being profitable, the well is plugged using cement. This is to prevent any ground water from coming in contact with the wellbore. The "API recommends setting cement plugs to isolate hydrocarbon and injection / disposal intervals, as well as setting a plug at the base of the lowermost USDW present in the formation (EPA, 2011, p. 16)." Figure 25 below shows a plugged well in the Marcellus Shale Region.

Figure 25: Plugged Well

(Range Resources, 2010)

2.5 Different Perspectives

Drilling for the natural gas in the Marcellus Shale has far reaching implications involving a number of different parties, many of whom have conflicting interests. From the very beginning of the drilling to the commercial distribution of gas, there are numerous people, communities, companies, and organizations that are involved and affected by the extraction process. The issues introduced by drilling the Marcellus Shale are very political in nature, and the different parties involved have a vested interest in any specific policy and legal changes to the status quo. All of these different people and organizations form a complex web of relationships that give shape to one of today's hottest, and most politically charged, issues.

Some of the most important groups involved in this complex field of play are the drilling companies themselves. The relationship between the drilling companies and local populations is generally multifaceted and complex. In many cases, local landowners lease their land to drilling companies for an initial profit and a share of royalties for the gas produced on their land. While some landowners make money in the process, some feel that drilling is responsible for damage done to their land and communities (The gas dilemma, 2011, p.46). In addition, local, state, and federal governments are faced with the task of developing and implementing regulation that can protect local populations and the environment without stifling the growth of a potentially huge and beneficial industry. Finally, because this topic has received extensive media attention, public opinion also plays a significant role in the unfolding events.

2.6 Regulation

Shale gas extracted from the Marcellus Shale is a valuable asset to the U.S. energy market and helps to bolster our country's energy security. Not only can the use of locally harvested shale gas help reduce our country's dependence on foreign oil, it is also a cleaner burning and more environmentally friendly fuel than conventional fossil fuels such as gasoline, diesel and coal. The main roadblocks standing in the way of shale gas becoming one of the primary sources of energy in the United States are the potential contamination of groundwater (and drinking water) near drilling sites due to the possible failure of the cement well casings, which may lead to the migration of methane. In order for shale gas to reach its full potential here in the United States, regulations at both the state and federal levels must be put in place in order to avoid potential environmental harm as well as health and safety problems.

2.6.1 Federal Regulations

The current regulations in place at the federal level are believed by some to be inadequate because they leave much of the responsibility to protect the public and the environment to the individual states. Since 2008, there have been over 1,400 recorded regulatory violations concerning drilling in the Marcellus Shale play (Legere, 2010). However, the varying severity of these violations has not yet been fully assessed. The type of violations can range from paperwork disputes to evidence of negligence by the drilling company. Nevertheless, these violations may be partly due to the fact that the rapid growth of the shale gas industry is a relatively recent development in the United States. New hydraulic fracturing techniques used in combination with horizontal well drilling allow shale gas to be more efficiently harvested than ever before. The short time between the development and implementation of these techniques in eastern United States has created a disparity between the rapid rate at which the shale gas industry is developing and the rate at which the necessary infrastructure can be developed. The federal regulations in place, Clean Water Act (CWA), the Clean Air Act (CAA), the Resource Recovery and Conservation Act (RCRA) etc., permit the protection of the environment and the public yet leave responsibility to the state to further regulate. Continuing the trend of improving the industry will require regulators and operators alike to perform at a high level and on a consistent basis to advance safe and sustainable shale gas development.

2.6.2 State Regulations

Currently, with the lack of specific federal regulations designed to address the unique challenges of shale gas and other unconventional fuels, the responsibility for protecting the public and the environment is left to the individual states. This decentralized approach allows for some variation in practice from state to state. In addition, a number of states including Arkansas, Louisiana, Michigan, New York, Oklahoma, Texas, West Virginia, and Wyoming have formed the Interstate Oil and Gas Compact Commission (IOGCC), which allows member states to focus on common issues together. New York and West Virginia are two IOGCC states in the Marcellus Shale who, along with Pennsylvania, have implemented new regulations strengthen well construction guidelines, hold drillers responsible for restoring or replacing water sources that are contaminated by drilling. Additionally, they require drillers to notify the DEP immediately if wells are over-pressurized and if casings are defective or if gas has migrated into drinking water sources. These regulations have been designed to help the shale gas industry to grow and prosper in a way that regulates the impact of gas development on local communities and the surrounding environment where drilling takes place.

2.6.3 State Regulation Locations

Tables 1 and 2 describe the state violations for Pennsylvania and West Virginia respectively. Figure 26 shows the various locations on a well where these violations apply.

Violation Code	Description	Well Location
207B	Failure to case and cement to prevent migrations into fresh groundwater	Surface Casing
78.83GRNDWTR	Improper casing to protect fresh groundwater	Surface Casing
78.83COALCSG	Improper coal protective casing and cementing procedures	Intermediate Casing
78.85	Inadequate, insufficient, and/or improperly installed cement	All Cement
78.84	Insufficient casing strength, thickness, and installation equipment	All Casing
209CASING	Inadequate casing	All Casing
78.81	Failure to minimize drilling disturbance and commingling of ground water	Surface Casing
79.12	Inadequate casing/cementing to prevent waste/blowout.	Entire Well / BOP
78.73A	Failure to construct and operate well in accordance with regulation, and ensure well integrity	Entire Well
78.73B	Failure to prevent drilling and other fluids from entering groundwater	Surface Casing
209BOP	Inadequate or improperly installed BOP, other safety devices, or no certified BOP operator	BOP
78.81D2PLAN	Failure to obtain proper approval for casing and cementing procedure for wells in storage and protective areas	Entire Well
78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days	All Cement

Table 2: Pennsylvania Cementing and Casing Violation Description and Well Location

Violation Code	Description	Well Location
22-6-7	Failure to case and cement to prevent migrations into fresh groundwater	Surface Casing
22-6-18	Improper coal protective casing and cementing procedures	Intermediate Casing
22-6-21	Improper surface casing	Surface Casing
22-6-31	Inadequate casing/cementing to prevent waste/blowout	Entire Well/ BOP

Table 3: West Virginia Cementing and Casing Violation Descriptions and Well Location

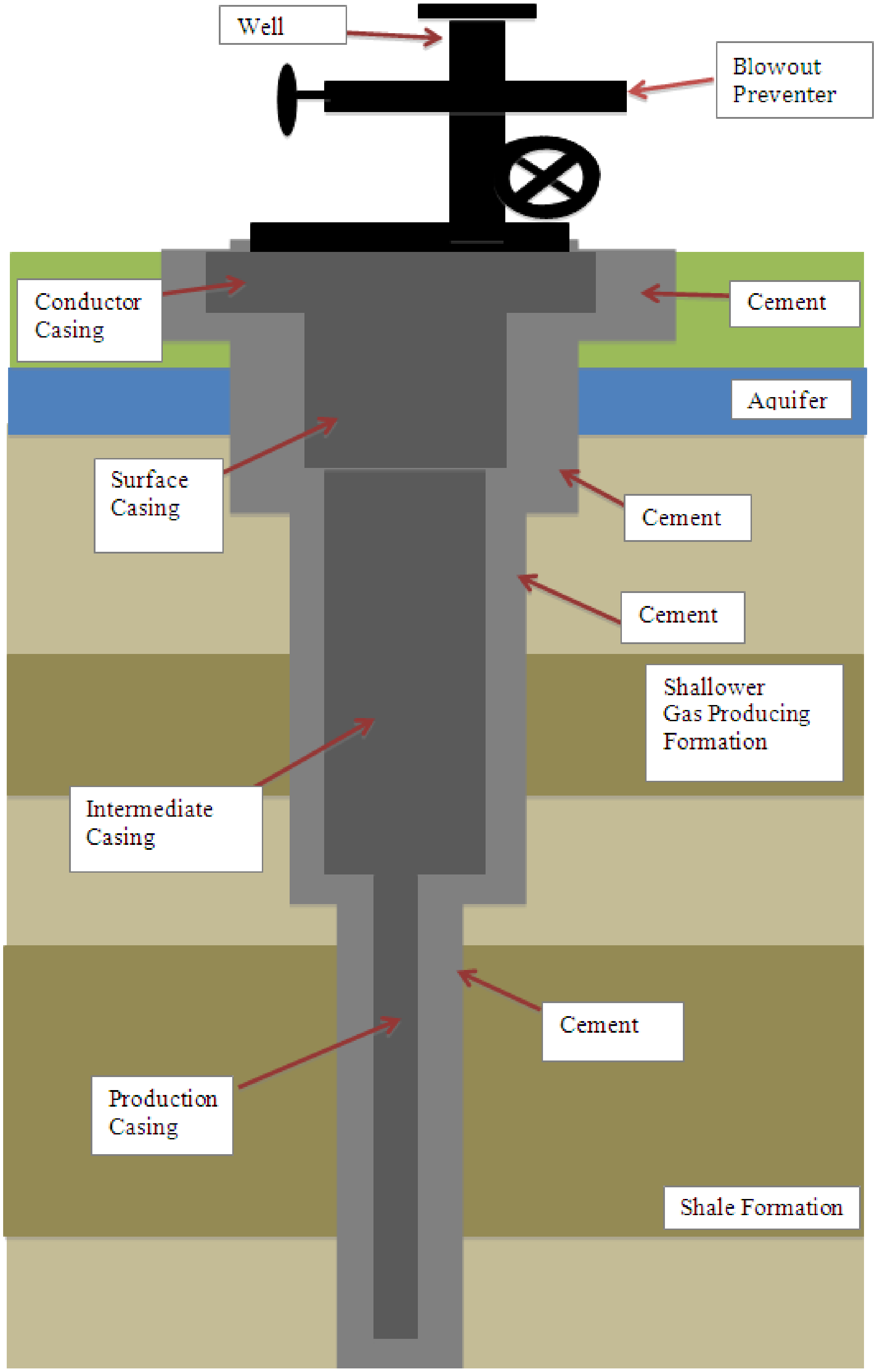


Figure 26: Well Diagram

2.7 Violation and Permit Data for Pennsylvania and West Virginia

The Pennsylvania DEP and West Virginia DEP keep records of a variety of oil and gas related activities. These records are made available electronically via the agencies' websites. Information pertaining to the Marcellus shale includes violation data as well as records of all Marcellus Shale permits issued within a state. The two different states present essentially the same information but in distinctly different ways, with Pennsylvania presenting their data in the form of spreadsheets and West Virginia maintaining a database.

2.7.1 Pennsylvania Violation Data Spreadsheets

The Pennsylvania DEP's Oil and Gas Office provides lists of all of the different drilling and administrative regulatory violations committed within the state. These violations are listed in spreadsheet form in Excel format. Each violation listing includes, among other things, the responsible operator, a permit number for the specific well location, a violation code, violation description, and date of infraction. The violation code is an important string of numbers and letters that denotes the specific type of violation. For instance, violation code 78.83GRNDWTR is used when the operator has failed to properly case to protect fresh groundwater, including not meeting the required depth standard. Similarly, violation code 78.86 corresponds to a failure to report defective, insufficient, or improperly cemented casing within 24 hours or submit a plan to correct within 30 days. Incidents listed in the raw data spreadsheets include, but are not limited to, cementing and well casing violations. Each year has a separate spreadsheet including violations occurring within that specific year. It is important to note that data from 2011 includes violations issued before October 31. A small subsection of the raw data provided by the state of Pennsylvania is shown in Figure 27. This figure does not include all of the information fields or all of the violation entries. Instead, it is included to illustrate the format and nature of the violation data provided by the state of Pennsylvania.

Operator1	Permit#	County	Municipality	Marcellus	Insp Id	Viol Id	Enf Id	Date Inspected	Date Violation	Violation Code	Violation Desc
ALTA OPR CO LLC	115-20231	Susquehanna	Middletown	Y	1876302	585002	256829	08-Apr-2010	08-Apr-2010	105.11	Person constructed, operated, maintained, modified, enlarged or abandoned a water obstruction or encroachment but failed to obtain Chapter 105 permit.
ALTA OPR CO LLC	115-20231	Susquehanna	Middletown	Y	1884711	587088	257806	08-Apr-2010	08-Apr-2010	102.4	Failure to minimize accelerated erosion, implement E&S plan, maintain E&S controls. Failure to stabilize site until total site restoration under OGA Sec 206(c)(d)
ALTA OPR CO LLC		Susquehanna	Middletown	Y		587089				78.56FRBRD	Failure to maintain 2' freeboard in an impoundment
ALTA OPR CO LLC		Susquehanna	Middletown	Y		587090				691.1	Clean Streams Law-General. Used only when a specific CLS code cannot be used
ALTA OPR CO LLC	115-20193	Susquehanna	Middletown	Y	1888330	588385	259426	28-May-2010	28-May-2010	102.4	Failure to minimize accelerated erosion, implement E&S plan, maintain E&S controls. Failure to stabilize site until total site restoration under OGA Sec 206(c)(d)
ALTA OPR CO LLC		Susquehanna	Middletown	Y		588386				78.56FRBRD	Failure to maintain 2' freeboard in an impoundment
ALTA OPR CO LLC		Susquehanna	Middletown	Y		588387				78.56PITCNST	Impoundment not structurally sound, impermeable, 3rd party protected, greater than 20" of seasonal high ground water table
ALTA OPR CO LLC		Susquehanna	Middletown	Y		588388				691.1	Clean Streams Law-General. Used only when a specific CLS code cannot be used
ALTA OPR CO LLC		Susquehanna	Middletown	Y		588389				601.101	O&G Act 223-General. Used only when a specific O&G Act code cannot be used
ALTA OPR CO LLC	115-20214	Susquehanna	Forest Lake	Y	1899433	591484	260888	19-Jul-2010	19-Jul-2010	78.56(1)	Pit and tanks not constructed with sufficient capacity to contain pollutional substances.
ALTA OPR CO LLC		Susquehanna	Forest Lake	Y		591485				691.1	Clean Streams Law-General. Used only when a specific CLS code cannot be used

Figure 27: Excerpt of Pennsylvania Data Sheet

(Pennsylvania Department of Environmental Protection, 2011)

2.7.2 Pennsylvania Permit Data Spreadsheets

In addition to the violation data, the state of Pennsylvania provides tables of all of the different permits granted within their borders. Marcellus drilling permits are only a fraction of the permits in these sheets. These tables, just like the violation data tables, are publically available on the Pennsylvania DEP website. Information in these tables includes permit number, the depth of the well, the well operator, county, and location in latitude and longitude coordinates. Some of the details not included about a specific well in the violation data can be found in the permit spreadsheet using the unique permit number. A small subset of the permit data is shown in Figure 28.

County Name	Municipality Name	Auth Id	Date Disposed	Other Id	Marcellus Shale Well	Horizontal Well	Well Type	Site Name	Total Depth	Latitude Decima	ngitude Decim	Operator
Allegheny	Aleppo	868846	03/29/2011	003-22174			OIL	MERLE MINICK UNIT 2 (	2500	40.52860278	-80.12187222	AMER NATURAL RESOUI
Allegheny	Aleppo	869305	04/04/2011	003-22175			OIL	MERLE MINICK UNIT 1 (	2500	40.53353056	-80.12285556	AMER NATURAL RESOUI
Allegheny	Elizabeth	865200	02/14/2011	003-22163			GAS	S HOLLAND 001 OG W	6500	40.22625278	-79.81302222	KRIEBEL MINERALS INC
Allegheny	Elizabeth	870934	03/29/2011	003-22178			GAS	YCC ASSOCIATES LP (	6500	40.30308333	-79.81552778	KRIEBEL MINERALS INC
Allegheny	Elizabeth	870953	03/30/2011	003-22179			GAS	YCC ASSOCIATES LP (	6500	40.30573056	-79.81657778	KRIEBEL MINERALS INC
Allegheny	Elizabeth	870826	04/04/2011	003-22177			GAS	S HOLLAND 002 OG W	6500	40.22554167	-79.80857500	KRIEBEL MINERALS INC
Allegheny	Elizabeth	870453	04/06/2011	003-22176			GAS	R ZIEGLER 003 OG WE	NULL	40.22030556	-79.81096111	KRIEBEL MINERALS INC
Allegheny	Elizabeth	874892	04/19/2011	003-22183			GAS	R ZIEGLER 002 OG WE	6500	40.22138611	-79.81425833	KRIEBEL MINERALS INC
Allegheny	Elizabeth	874926	04/19/2011	003-22184			GAS	R ZIEGLER 004 OG WE	6500	40.21731944	-79.81394167	KRIEBEL MINERALS INC
Allegheny	Elizabeth	897089	10/17/2011	003-22151			GAS	A SOFFA 001 OG WEL	6500	40.29751944	-79.81938056	KRIEBEL MINERALS INC
Allegheny	Fawn	877931	05/18/2011	003-22189			GAS	TFIT 1-104.8 OG WELL	3400	40.66579444	-79.76903333	BLX INC
Allegheny	Forward	879094	05/18/2011	003-22128	Y	Y	GAS	OLIVER WEST 590591	7800	40.24313889	-79.90597222	EQT PRODUCTION CO
Allegheny	Forward	879080	05/18/2011	003-22129	Y	Y	GAS	OLIVER WEST 590590	7800	40.24316667	-79.90591667	EQT PRODUCTION CO
Allegheny	Forward	886014	07/12/2011	003-22192			GAS	W GRAFF 001 OG WEL	3500	40.20580556	-79.87558333	KRIEBEL MINERALS INC
Allegheny	Forward	891885	09/12/2011	003-22198		Y	GAS	GRAFF W UNIT 01H OG	2917	40.20664167	-79.87706667	KRIEBEL MINERALS INC
Allegheny	Forward	891885	09/12/2011	003-22198		Y	GAS	GRAFF W UNIT 01H OG	5500	40.20664167	-79.87706667	KRIEBEL MINERALS INC
Allegheny	Forward	895333	10/25/2011	003-22147			GAS	C LARGE 001 OG WEL	3500	40.21102778	-79.88620000	KRIEBEL MINERALS INC
Allegheny	Frazer	875030	05/11/2011	003-22185			GAS	DIAZ 105-1 OG WELL	4000	40.62172222	-79.77893333	HUNTLEY & HUNTLEY INC
Allegheny	Frazer	889859	08/12/2011	003-22193	Y	Y	GAS	YUTE UNIT 2H OG WEL	7120	40.57308056	-79.80693056	RANGE RESOURCES AP
Allegheny	Frazer	889883	08/12/2011	003-22194	Y	Y	GAS	YUTE UNIT 3H OG WEL	7120	40.57312222	-79.80683889	RANGE RESOURCES AP
Allegheny	Frazer	889909	08/12/2011	003-22195	Y	Y	GAS	YUTE UNIT 5H OG WEL	7120	40.57321667	-79.80691389	RANGE RESOURCES AP
Allegheny	Frazer	889916	08/12/2011	003-22196	Y	Y	GAS	YUTE UNIT 8H OG WEL	7120	40.57303611	-79.80702500	RANGE RESOURCES AP
Allegheny	Frazer	889924	08/12/2011	003-22197	Y	Y	GAS	YUTE UNIT 9H OG WEL	7120	40.57313056	-79.80709722	RANGE RESOURCES AP
Allegheny	Glassport	860602	01/12/2011	003-22160			GAS	P MILLER 001 OG WEL	6500	40.33958056	-79.88431389	KRIEBEL MINERALS INC

Figure 28: Excerpt of Pennsylvania Permit Data

(Pennsylvania Department of Environmental Protection, 2011)

While the violation data was ripe with potential insights, there were flaws and intricacies in the data that were important to understand. For instance, in Pennsylvania, some of the violations are listed multiple times. Each permit number corresponds to a unique well location. While it is possible for one unique permit number to have several violations with different violation codes, recurring violations with the same violation code should not reasonably occur within days or even months of each other. The same wells simply do not get penalized for the same violation over and over again[1]. Regardless, the same violations sometimes appear in the data for the same well within a short period of time. This does not necessarily indicate actual recurring violations. Instead, duplicate violations are a byproduct of the way that the spreadsheets were generated. What may appear to be a duplicate violation is often actually a different, often administrative, 'action' taken on behalf of that same violation. This 'action' is then listed in the spreadsheet with the same permit number.

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[1] This assertion was confirmed in our interviews with inspectors in the state of Pennsylvania

2.7.3 West Virginia Violation Database

Unlike in Pennsylvania, West Virginia violation data is made available in a searchable database rather than in spreadsheet form. Figure 29 shows the search page for the oil and gas violations database. Users can search for violations by entering a date range. These results can be further filtered by county, operator name, and enforcement officer. Results are returned in spreadsheet form and can be pasted into Excel for analysis. Each entry contains a violation ID, the date of occurrence, operator name, violation code etc. A small subset of violation data returned by a sample search is shown in Figure 30.

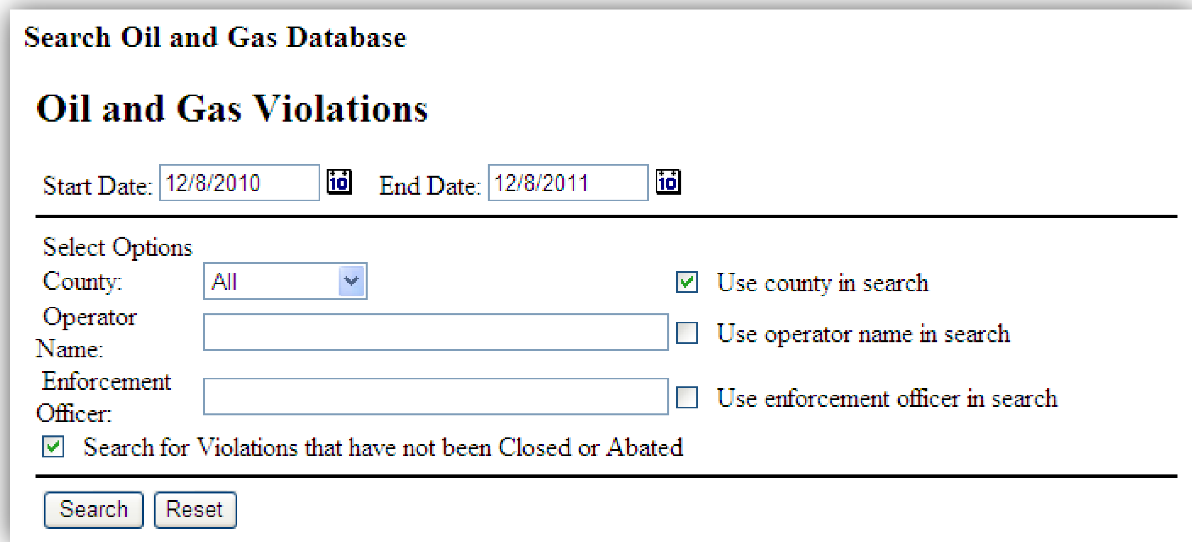

Figure 29: West Virginia Search Feature

(West Virginia Department of Environmental Protection, 2011)

Oil and Gas Violations Data

141 rows returned.

Violation ID	Old Violation Number	Violation Date	API	Operator	WV Code/Reg
8668		12/05/2011	051-01328	CHESAPEAKE APPALACHIA, L.L.C.	22-6-3(a)
8669		12/05/2011	051-01328	CHESAPEAKE APPALACHIA, L.L.C.	22-11-6
8666	8666	11/23/2011	017-05918	EQT PRODUCTION COMPANY	22.6.3-35.17.1
8665	8665	11/16/2011	017-05996	JAY-BEE OIL & GAS	22.6.6
8665	8665	11/16/2011	017-05996	JAY-BEE OIL & GAS	22.6.6
8664	8664	11/15/2011	079-00727	VIKING ENERGY CORPORATION	35-1-7-19
8663	8663	11/15/2011	079-00727	VIKING ENERGY CORPORATION	22-6-7

Figure 30: West Virginia Data

(West Virginia Department of Environmental Protection, 2011)

3. Methodology

The goal of our project was to produce a detailed analysis of available data for review by the DOE. Furthermore, the team sought to identify and interpret any trends observed in the data. Our methodology was aimed to accomplish these two goals through the use of multiple techniques including interviews, site visits, and computer based data analysis tools. These techniques allowed our group to visually interpret the data and make informed conclusions based on knowledge gained from expert individuals. The following section details how the group accomplished these two core objectives.

3.1 Analysis of Public Data

In order to identify trends relating well casing and cementing violations to other outside factors, our group analyzed the public data made available by the states of West Virginia and Pennsylvania. Because of time constraints, West Virginia analysis was only preliminary and is not included in the results. The thorough analysis of Pennsylvania's data was aimed at filling a gap identified by the Secretary of Energy's Advisory Board (SEAB) in their 90-day report on the shale gas industry. The SEAB stated there was a "vast amount of data that is publically available, but there are surprisingly few published studies of this publically available data (Secretary of Energy Advisory Board , 2011)." In order to fill this gap, our group evaluated, refined, and analyzed the data that is publically available. The following techniques were used to uncover important trends within the violation data.

3.1.1 Visual Representation of Data

In an effort to visualize the data and identify trends, our group used Microsoft Excel to produce graphs, tables, and charts that represent the violation data in a meaningful way. This process involved refining the state violation spreadsheets to include only violations related to well casing and cementing. Also, due to the manner in which these spreadsheets were generated, some of the same violations were listed multiple times. For the purpose of this project, we concluded that any violation entries in the Pennsylvania spreadsheet occurring in the same year with the same violation code and permit number were the same violation[2]. All such duplicates were removed and not included in our analysis. Once the data sets were finalized, Excel's graphing functions were used to identify trends and correlations relating violations to other factors such as operating company and time of year.

3.1.2 Geographical Plots of Violations Using MATLAB

MATLAB was used to plot cementing and well casing violations on specific locations of each state. These plots allowed for a geographical visualization of the data and the identification of trends related to location. In the public violation spreadsheets, a permit number for the specific well where each violation occurred is listed. In Pennsylvania, each well has a unique permit number. Pennsylvania DEP keeps detailed records of all of the permits that are granted within their borders. Included in these records are latitude and longitude coordinates for the proposed location of each well. The group produced a function in MATLAB that matched each violation to its latitude and longitude location using the permit number. A separate MATLAB function was used to plot violation locations on a map based upon the latitude and longitude data produced by the first MATLAB function. These plots allowed us to identify important clusters of violations in certain regions.

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[2] This conclusion is based upon a series of interviews conducted with inspectors in the state of Pennsylvania. According to these inspectors, multiple entries in the spreadsheets of the same violations reflect the different administrative steps involved in dealing with a violation rather than the same violation occurring multiple times within a short time frame. The other findings from these interviews will be further discussed in the results portion of this report.

3.2. Explanations for Observed Trends and Identify Areas for Further Research

In order to elucidate our findings, our group collected further information related to the trends that we observed in the graphs. The group sought out information to specifically address questions that arose during data analysis. The group used this information to provide the DOE with possible explanations for any trends observed in the data. Given the time restrictions and the complex nature of the issues, a complete and definitive explanation for all of the data trends was not a reasonable expectation. For this reason, identifying areas where more research needs to be completed was an important part of this project. The following two techniques were used to develop some potential explanations for phenomena observed during data analysis and to identify areas in which more research needs to be done.

3.2.1 Interviews with People Competent in the Cementing or Inspection Process

Many of the questions that arose during the data analysis phase of this project were best answered by conducting interviews with people directly involved in the cementing or inspection process. Specifically, interviews with inspectors from Pennsylvania's DEP served an important role in clarifying the exact meaning of certain violations and violation codes. Inspectors were also able to answer questions about the nature of the data and provide more information about how they look for and identify certain violations. Interviews with government officials within the DOE, EPA, and state DEP offices shed light on the broader organization of the inspection process. Lastly, interviews with drilling company representatives allowed us to more clearly understand the industry's viewpoints.

3.2.2 Site Visits to Drilling Locations

There are some drilling companies who have expressed an interest in being more open and transparent about their drilling practices in an effort to ensure the public that they are operating in an environmentally friendly manner. One of these companies, Range Resources, generously took our group on a tour of some of their drilling facilities in Canonsburg, Pennsylvania. While in Canonsburg, we saw wells in the drilling, fracturing, and production stages. Talking to employees who were directly involved in the cementing process allowed the group to ask probing questions related to the data analysis results. While visiting the drilling site was hugely informative, it is important to note that the specific facilities that a Range chose to showcase may be carefully selected and among their best.

3.3. Summary

In order to accomplish the core project objectives, our group collected violation data from the Pennsylvania DEP. This data was visualized and analyzed for trends related to geographical location, operator, and seasonal factors using Excel and MATLAB. These trends were then examined and explained using further research and interviews with experts and people involved in the cementing and inspection processes. When trends were too complicated to explain definitively within the limited time frame of this project, future areas of research were identified.

4. Interview Summaries and Site Visit

Interviews were an important part of the research process for this project. The group consulted with a number of different people from a variety of different backgrounds. Interviewees included drilling company representatives, employees at the Pennsylvania DEP, EPA employees, and academics. All of these individuals are listed in the order that we talked to them in Table 3 below. The table is followed by a description of some key things they taught us.

Interviewee	Company/Agency	Title/division
Ken Kennedy	PA-DEP	Inspector
Natenna Dobson	DOE-FE	Physical Scientist
Nancy Johnson	DOE-FE	Supervisory Environmental Scientist
Anthony R. Ingraffea	Cornell University	Civil and Environmental Engineering Professor
Mike Panettieri	PA-DEP	Oil and Gas Inspector Supervisor
Christopher Knopes	EPA	Director National Planning, Measures, and Analysis
Nick Cerone	Range Resources	Petroleum Engineer
Mike Mackin	Range Resources	Communications Manager
Scott Perry	PA-DEP	Acting Deputy Secretary of Oil and Gas Management

Table 4: Table of Interviewees

4.1 Ken Kennedy, 11/8/2011

Oil and Gas Inspector

Pennsylvania Department of Environmental Protection

Mr. Kennedy is responsible for conducting state oil and gas inspections in several townships in Bradford County, Pennsylvania. He explained the inspection process as well as how a site is chosen for inspection. According to Mr. Kennedy, the process begins with a Spud Report from the state. The Spud Reports include the operator doing the drilling and the time at which they will be putting in the conductor casing. The state receives a notification of drilling, which is sent to the oil and gas inspector in the appropriate area. The first inspection is of the top hole rig, which includes the first forty feet of casing. This inspection is followed by subsequent inspections during the placement and cementing of each casing section. The inspections are performed as the casings are being cemented or just after completion. From this interview, our group learned that typically the well operators do not do the cement jobs. Instead, contractors like Halliburton or Schlumberger perform them. In addition, we found that cementing is inspected while the cement is being poured. The operator must take three samples from the cement job: one at the beginning, one at the middle, and one at the end. Also, after the well is completed, there are follow up inspections that are either randomly selected or come from tips provided by people like home owners with a change in their water supply. Each inspector completes roughly 20 to 25 inspections a week. In addition, to qualify as an inspector, one must have an extensive background in oil and gas, take a civil service examination, and complete a following interview process. Mr. Kennedy also stated that, as a whole, the industry seems to be getting better about designing wells that cater to specific geological and geographical variations found at different drilling sites.

4.2 Natenna Dobson, 11/15/2011
Physical Scientist

Fossil Energy - Department of Energy

Ms. Dobson is an environmental scientist who provided information on the inner workings of the natural gas industry at the state level. She explained that states need more man, computer data collection, and analysis power due to the growing workload associated with shale gas development. She spoke about the roles of many agencies and organizations such as the American Petroleum Institute (API), the Marcellus Shale Coalition (MSC), and the Interstate Oil and Gas Compact Commission (IOGCC). The API provides suggested standards on a national scale, while the MSC recommends best practices based on specific states. The IOGCC is an organization that allows states to focus on mutual issues together and develop best practices for the oil and gas industry. Another point that Natenna brought up was the fact that the geology throughout the Marcellus Shale region is not consistent. She mentioned that drilling sites in different locations need different constructions due to the variations in subsurface geology. For example, when drilling to the Marcellus Shale through younger, shallower hydrocarbon formations, more care and different practices may be necessary to prevent migration of methane.

4.3 Nancy Johnson, 11/15/2011
Supervisory Environmental Scientist

Fossil Energy - Department of Energy

Ms. Johnson serves as a program contact in the Fossil Energy department of the DOE. During our interview, she explained that one of the major issues associated with the Marcellus Shale is that they are unaware of the exact water table depth. She also explained that the drilling and design engineers decide the specifications of the well and these are reviewed in the well proposal. She stressed the necessity of improving the state's in-house data management systems. She also mentioned the practice of injecting carbon dioxide into wells to displace gas or oil and enhance recovery. She then explained the role of the State Review of Oil and Natural Gas Environmental Regulations (STRONGER). This organization provides state-by-state analysis of hydraulic fracturing techniques and waste management procedures.

4.4 Anthony Ingraffea, 11/17/2011

Professor of Civil and Environmental Engineering

Cornell University

Professor Ingraffea runs the Control Fracture Group (CFG) at Cornell, where the mission is to create, verify, and validate computational simulation systems for fracture control. Our interview with him was valuable; he gave great insight into the technical issues related to the construction of a well. During our conversation, Professor Ingraffea clarified that a half an inch of cement around the casing was enough to support the structure. Also, a thicker layer of cement requires a larger hole to be drilled. For this reason, some companies use only the required amount of cement to avoid elevated costs. Professor Ingraffea provided information on topics including cement design, the purposes for using cement, and the importance of cement chemistry. Cement chemistry is especially important because the cement must maintain its liquid form while traveling over a mile through the wellbore. Our conversation also covered the dangers associated with drilling through shallow gas bearing formations in order to get to the Marcellus Shale. Professor Ingraffea explained that the gas stored in these formations can be released during drilling. As the gas leaks out of these shallower formations during the cementing process, the flow of gas can create channels in the cement. These channels can likely act as a pathway for methane migration. Another concern brought up in our interview relates to corrosion of the well casing. The fracturing fluid has an anti-corrosive additive. As methane comes up through the well it brings with it the proppant, sand, which etches away the anti-corrosive. This can potentially lead to corrosion of the casing.

4.5 Mike Panettieri, 11/18/2011

Oil and Gas Inspector

Pennsylvania Department of Environmental Protection

Mr. Panettieri is an oil and gas inspector in Pennsylvania who proved to be a valuable resource. He has been involved with the drilling industry for fifteen years. He answered some of our questions about the data including the difference between the date of inspection and the date of violation. The violation date refers to the date that a violation occurred. Our group was informed that an enforcement ID corresponds to an enforcement action such as the issuing of a fine. He explained to us that a violation ID from the violation sheets corresponds to a specific violation. We found out that the electronic system used by the inspectors for reporting violations is called e-facts. He told us that there are multiple inspections of the cement during the life of a well. At cement jobs inspectors and operators look for what type of cement, additives, equipment calibration, pump rates, if the cement returns to the surface, the chemistry of the mix used, and a check for loss of circulation. The cementing company collects samples of the cement being pumped into the bore hole, typically using a plastic cup.

4.6 Christopher Knopes, 11/18/2011

Director of National Planning, Measures, and Analysis

Office of Enforcement and Compliance Assurance - Environmental Protection Agency

Mr. Knopes works in the Office of Enforcement and Compliance Assurance at the EPA Headquarters. He suggested that the EPA region three offices would have more relevant information relating to our project. He identified Samantha Beers as a person of interest within region three. The EPA is currently investigating the shale gas industry by first looking at the broad scope of issues, then narrowing their focus to specific problems. This investigation is aimed at informing states and other agencies on how to best focus the funding and manpower and will take a large amount of time complete. He also mentioned that the EPA hoped to establish a true federal role in the shale gas industry and develop a large knowledge base and pass on information to states. He noted that, currently, ninety percent shale gas well inspections are done by state agencies as opposed to the EPA. He also said that some states use risk based inspections or smart enforcement but this process is usually not utilized to its true potential. His final points covered how each site can present different challenges to inspectors.

4.7 Range Resources Site Visit 12/2/11
Mike Mackin – Communications Manager
Nick Cerone – Petroleum Engineer

Mike Mackin is a Communications Manager at Range Resources regional headquarters. Nick Cerone is a petroleum engineer for Range and has a great deal of experience in the field. Mr. Mackin led our tour and Mr. Cerone was able to answer many of our technical questions. On the bus to the first site, Mr. Makin explained many of Range's unique characteristics. Some of these include the fact that they operate mainly in the southwest portion of Pennsylvania and harvest both wet and dry gas. This is uncommon in the industry because some companies view wet gas, ethane, butane, and other hydrocarbons as an aggravation while Range sees it as an opportunity. Range sends their gas to a third party company for the separation of wet and dry gas. They incur this additional cost because these hydrocarbons are valuable. Range strives to exceed safety regulations by implementing non-required features such as a fifth layer of well casing and cementing and putting bird netting over their water impoundments. Furthermore, during well drilling and construction, Range ensures that no industrial or hydraulic fluids are able to come in contact with the surface. They do this by placing catch basins under any piece of equipment that touches fluids. When fluids, including rain water, accumulate in these basins, an environmental company must come to the site to collect and transport the water for proper treatment.

Apart from these unique characteristics, our group gained a lot of valuable information from conversations with Nick Cerone, a petroleum engineer who is responsible for designing and overseeing the construction of wells. For instance, he explained to us how the curvature of the wellbore is achieved; using a drill motor with a one to two degree bend to gradually turn the wellbore. Also, he explained that some testing devices, including the cement bond log (CBL), could produce results that can be interpreted differently by different people. He also toured us around a rig that was laying the production casing into the wellbore. The process of putting the casing in place involves moving each section of casing from the ground to the top of the derrick using a hydraulic lift and connecting each section of casing together using high torque power tongs. Once connected, the string of casing is lowered into the well and another section is lifted and attached. This process is repeated with each section of casing in a specific order until the string of casing reaches the bottom of the well. According to Mr. Cerone, some issues that can be encountered with the placement of the casing include improper threading which requires the whole string of casing to be removed and sent to be re-threaded. The string of casing can accidentally be dropped into the wellbore, which requires the operator to "go fishing for the casing." This entails lowering a tool into the wellbore in an attempt to find, secure, and remove the string of casing.

Our visit continued to a site where a string of casing was being cemented in place. Mr. Cerone explained the process of mixing the cement and pumping it into the wellbore. This process involves two cement trucks that are linked together. The first truck contains the powdered mix for the cement which is pumped into the second truck to be mixed with water. The cement is then pumped down the casing, out the bottom, and into the annular space between the casing and the outside rock formations. The wait time for cement to solidify is eight hours, as dictated by Pennsylvania state regulation. The cement is tested during pumping by dipping a plastic cup into the cement in the truck and letting it dry. The sample is then sent to a third party testing facility.

The third and final part of the visit took place at a well pad that was in the production phase. Mr. Makin explained the various safety features in use at the site, including a shutoff system that is activated when unauthorized changes are made to the wellhead. Also, static dissipaters are used to protect the site from lightning. In addition a device is located on the pad that collects any gas vapors and burns them safely.

4.8 Scott Perry 12/8/2011
Acting Deputy Secretary of Oil and Gas Management
Pennsylvania Department of Environmental Protection

Mr. Perry is currently the Acting Deputy Secretary of Oil and Gas Management for Pennsylvania’s DEP. During the interview he touched on a wide range of topics including issues with the public data, inspection process, and violation severity. He explained to our group the reasons why Pennsylvania’s online public data was not ideally presented. The data management system was originally developed for internal use and it is not best suited for the display of the public violation data. Some of the effects of this outdated system include the fact that any action regarding a violation is listed in the data sheet. This further explained the “duplicates” that our team had encountered in the data. Also, he spoke about how multilateral well pads had an effect on the data because when a violation is given to a single well on a multi-wall pad, the violation can be counted for each of the wells. He also explained that a single incident can violate multiple regulations. He stated that they plan on changing the data management system so that these multiple violations will be organized under one infraction. Mr. Perry also spoke about the way the state keeps record of inspections that don’t result in a violation. He told our group about the weekly workload reports and the year to date inspection reports, which can be found online.

The next line of questioning focused on the DEP inspectors and the inspection process that they employ. Mr. Perry spoke to the nature of the inspector workforce including the distribution of the inspectors throughout the state. The north-central region of the state has fewer inspectors than the northwest and southwest regions. The goal for the DEP is twenty inspections per inspector per month. He stated that inspections are assigned based on pad construction and drilling activity. Ideally, the DEP would like to meet with companies prior to well construction.

Also, the state receives notification when drilling is completed. He admitted that the amount of inspections is lower than he would like due to the development of multilateral well pads that take more time to inspect. Furthermore, he noted the distinction between the two categories of inspectors; Oil and Gas Inspectors and Water Quality Specialists. Oil and Gas Inspectors are focused on the inspection of the construction of the well, while Water Quality Specialists investigate environmental issues related to erosion, wastewater, and air quality. In order to be hired as an Oil and Gas Inspector, an individual must possess at least three years of rig experience. Mr. Perry pointed out the struggles of finding people who specifically worked on horizontal drilling rigs due to the gap in salary; drilling companies can pay as much as double what the government can offer. Mr. Perry also noted that the DEP has recently started to work with the EPA on oil and gas related issues. He also explained that the DEP has almost all of the responsibility when it comes to oil and gas issues due to the absence of a specific oil and gas commission.

One of the most important points that Mr. Perry made was about the fact that more cementing and well casing violations are seen in the northeast sector of Pennsylvania due to the unique geology of that region. Companies that have experience in other gas producing areas with relatively uniform subsurface environments had trouble adapting to the challenges of the northeastern Marcellus Shale. The challenges are mostly associated with the multiple shallow gas bearing formations located in north-central and northeast Pennsylvania. He noted that these formations can cause issues with the cementing process by leaking gas into the wellbore and forming channels in the cement, which can act as pathways for methane migration. Companies are developing ways to prevent these formations from interfering with their cementing practices. First, the companies drill one exploratory well to log the location of formations. This is used to plan where the intermediate casing should be placed and to determine what extra precautions should be taken when drilling other wells in this region. Mr. Perry was unable to explain why certain months had more cementing and well casing violations than others. Although, he did make it clear that it was not due to variation in the inspector workforce.

Another important aspect of our interview with Mr. Perry was a discussion of the violation hierarchy. Mr. Perry listed four categories of violations in order of severity. The most severe category of violations has to do with the migration of methane outside of the wellbore. The second most severe category of violations has to do with a threat to public health. The third category relates to violations regarding environmental harm. The least severe category of violations has to do with improper paperwork. Violation 78.86, the most common cementing and well casing violation given in 2011, relates to all four of these categories. Mr. Perry also explained the importance of replicating the conditions of the cement lab testing in the field. This includes knowing what exactly is going into the cement, what the pH and temperature of the mix water are, and the conditions of the subsurface geology. The final part of our conversation related to how some companies deal with the challenges of drilling in the north-central and northeastern regions. This region of the state contains shallower gas producing formations that have the potential to affect the drilling process.

5. Results and Analysis

In order to examine the public violation data and identify trends related to well casing and cementing, our group produced visual representations of the data using Microsoft Excel and MATLAB. The following section contains charts, graphs, and plots as well as noteworthy trends in the data and possible explanations for those trends. Many areas that need further research were also identified during the examination of the data. This section is organized into four subsections: Permitting and Drilling Analysis, Company Analysis, General Violation Analysis, and Specific Violation Analysis. Each section contains graphs and related explanations.

5.1 Permitting and Drilling Analysis

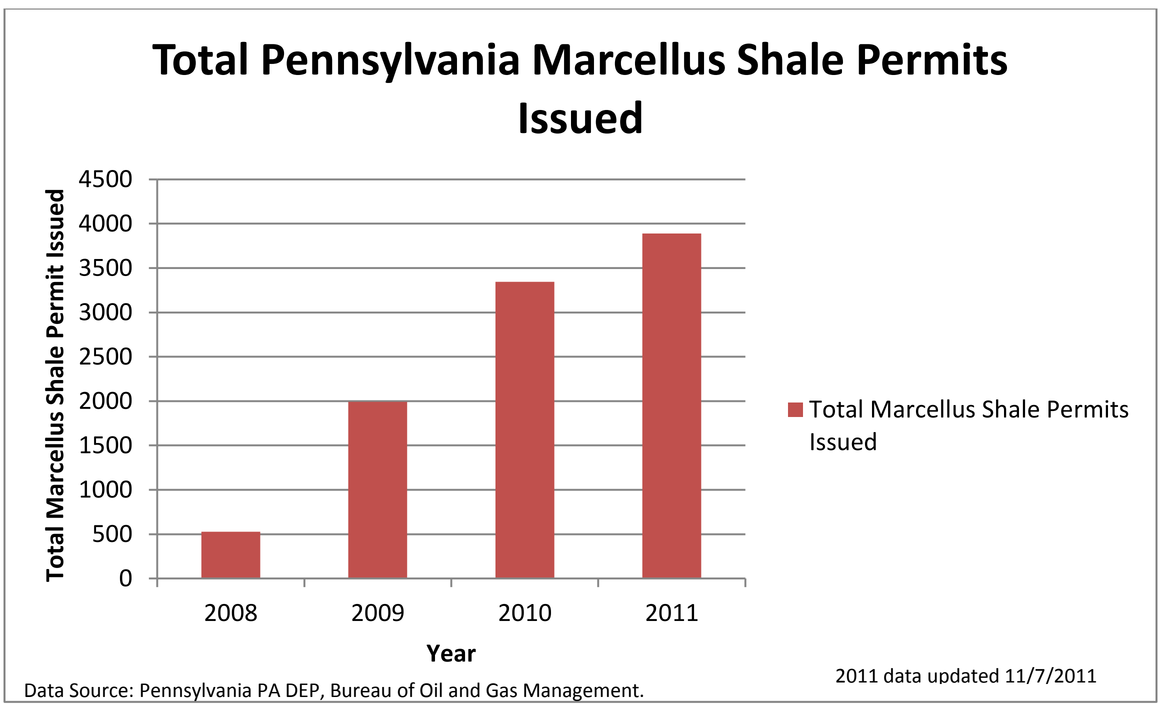


Figure 31: Total Pennsylvania Marcellus Shale Permits Issued

Figure 31 shows the total number of Pennsylvania Marcellus Shale drilling permits. The total amount of drilling permits issued has increased from year to year. In 2008, the Pennsylvania DEP issued 529 drilling permits. In only three years, this number increased to 3,888 permits.

This implies that the amount of drilling as well as the number of violations will continue to increase. With an increase in drilling of the Marcellus Shale there will need to be an increase in support from the state and the federal government. This may be in the form of more regulations or an increase in hiring of inspectors to ensure that the industry continues to operate at the highest quality possible.

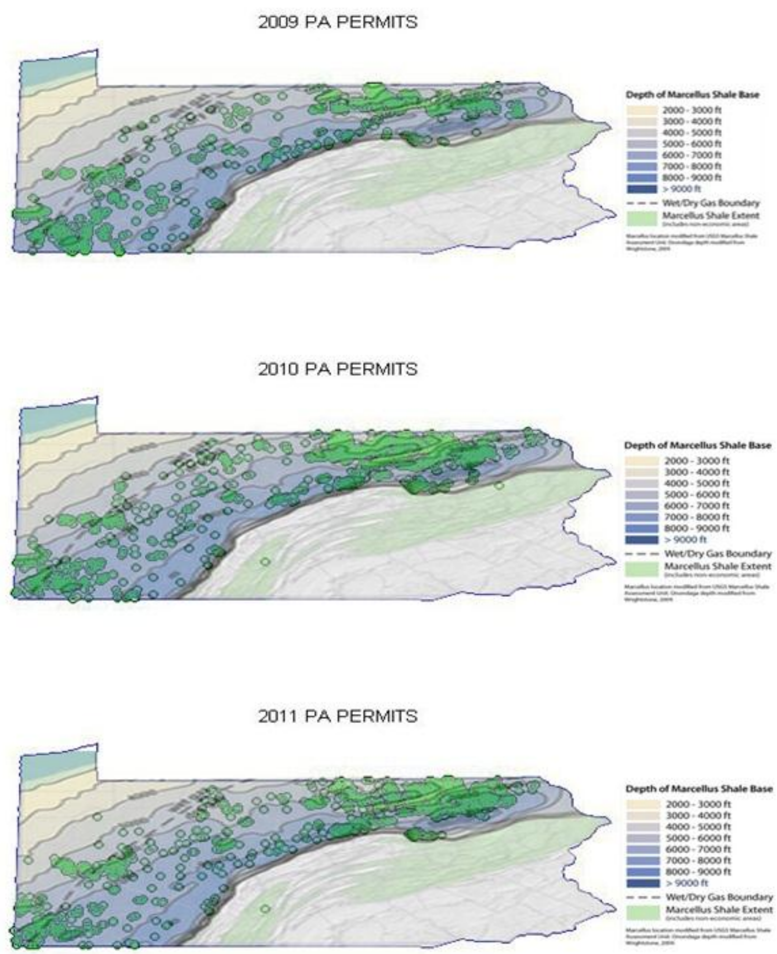
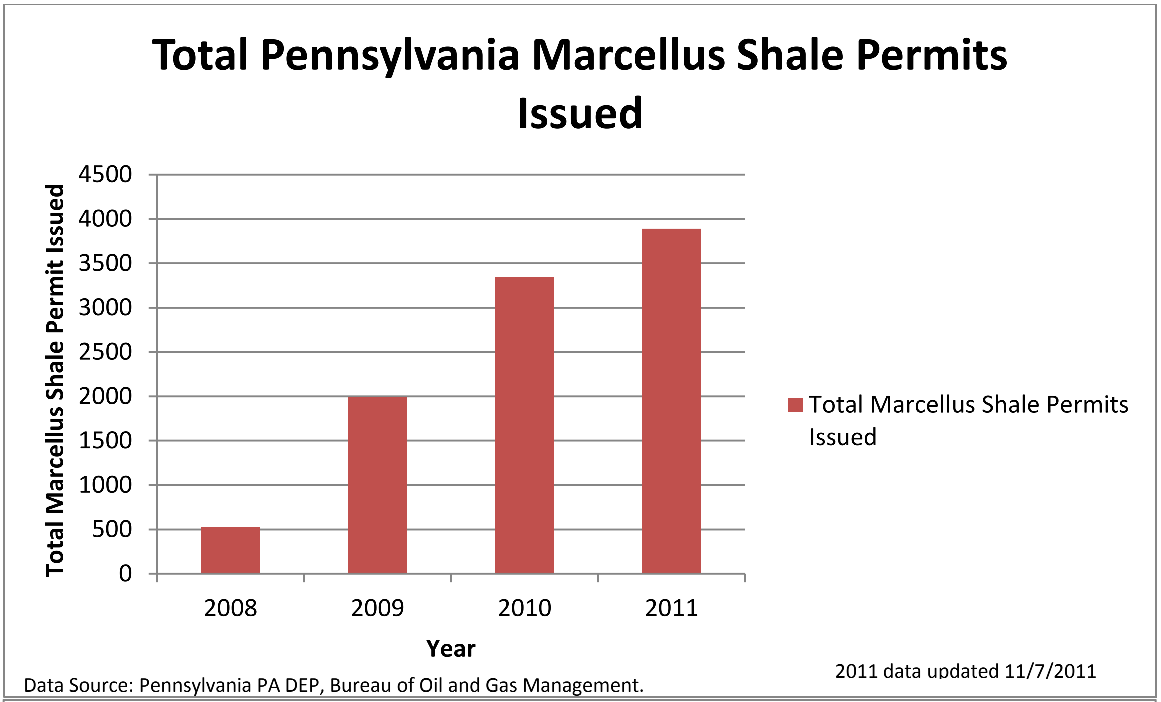


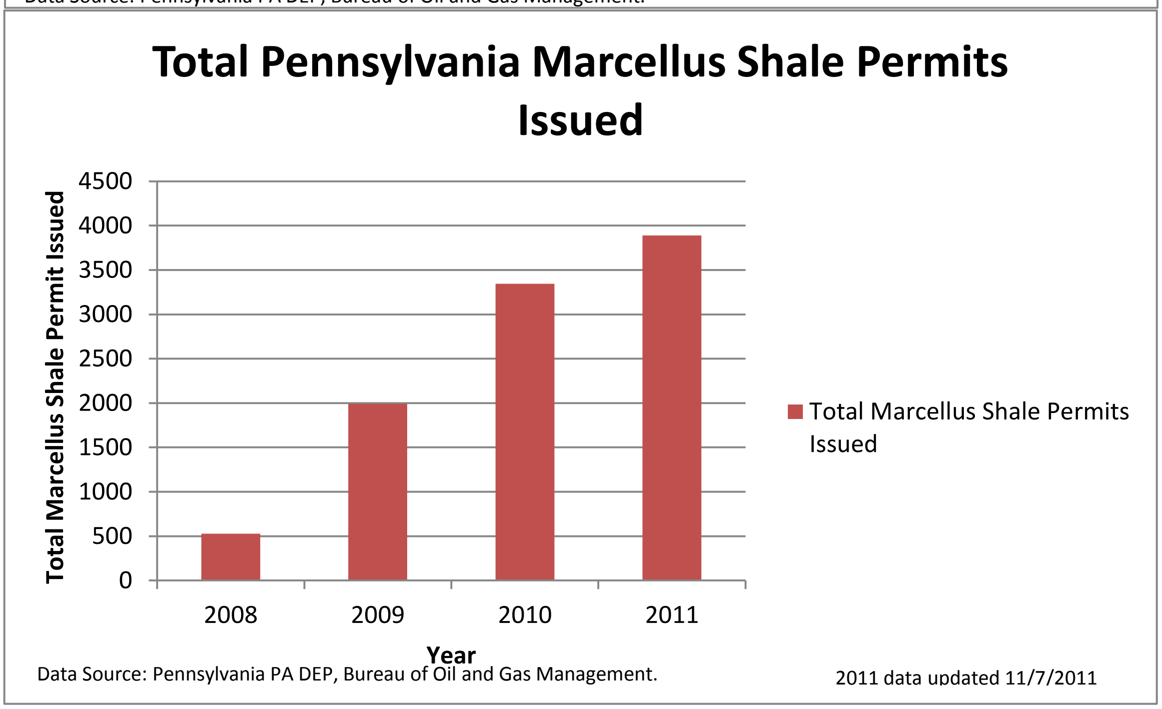
Figure 32: Pennsylvania Permit Activity

Figure 32 shows permit locations in the state of Pennsylvania for the years 2009, 2010, and 2011. Permit locations, in latitude and longitude coordinates, were gathered from the

Pennsylvania DEP. In the figure, green dots indicate permit locations. The depth of the Marcellus shale is suggested by the color scale. Darker blues correspond to deeper shale regions while the lighter colors represent more shallow areas.

From Figure 32, it is clear that permitting activity has shifted in the past few years. In 2009, there were altogether fewer permits in the state. Also, a greater percent of the permits are for the southwest portion of the state than for later years. Much more permitting activity, in the years 2010 and 2011, is seen in the northeastern part of the state. While this finding is significant, it is important to note that permits and actual wells drilled do not correspond on a one to one basis. In the year 2010, we found that only about 40% of the approximately 3,300 total permits assigned translated into wells actually drilled.


Total Pennsylvania Marcellus Shale Permits Issued
Total Marcellus Shale Permit Issued
4500
4000
3500
3000
2500
2000
1500
1000
500
0
2008
2009
2010
2011
Year
Total Marcellus Shale Permits Issued
2011 data updated 11/7/2011
Data Source: Pennsylvania PA DEP, Bureau of Oil and Gas Management.


Total Pennsylvania Marcellus Shale Permits Issued
Total Marcellus Shale Permit Issued
4500
4000
3500
3000
2500
2000
1500
1000
500
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2008
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2011
Year
Total Marcellus Shale Permits Issued
Data Source: Pennsylvania PA DEP, Bureau of Oil and Gas Management.
2011 data updated 11/7/2011

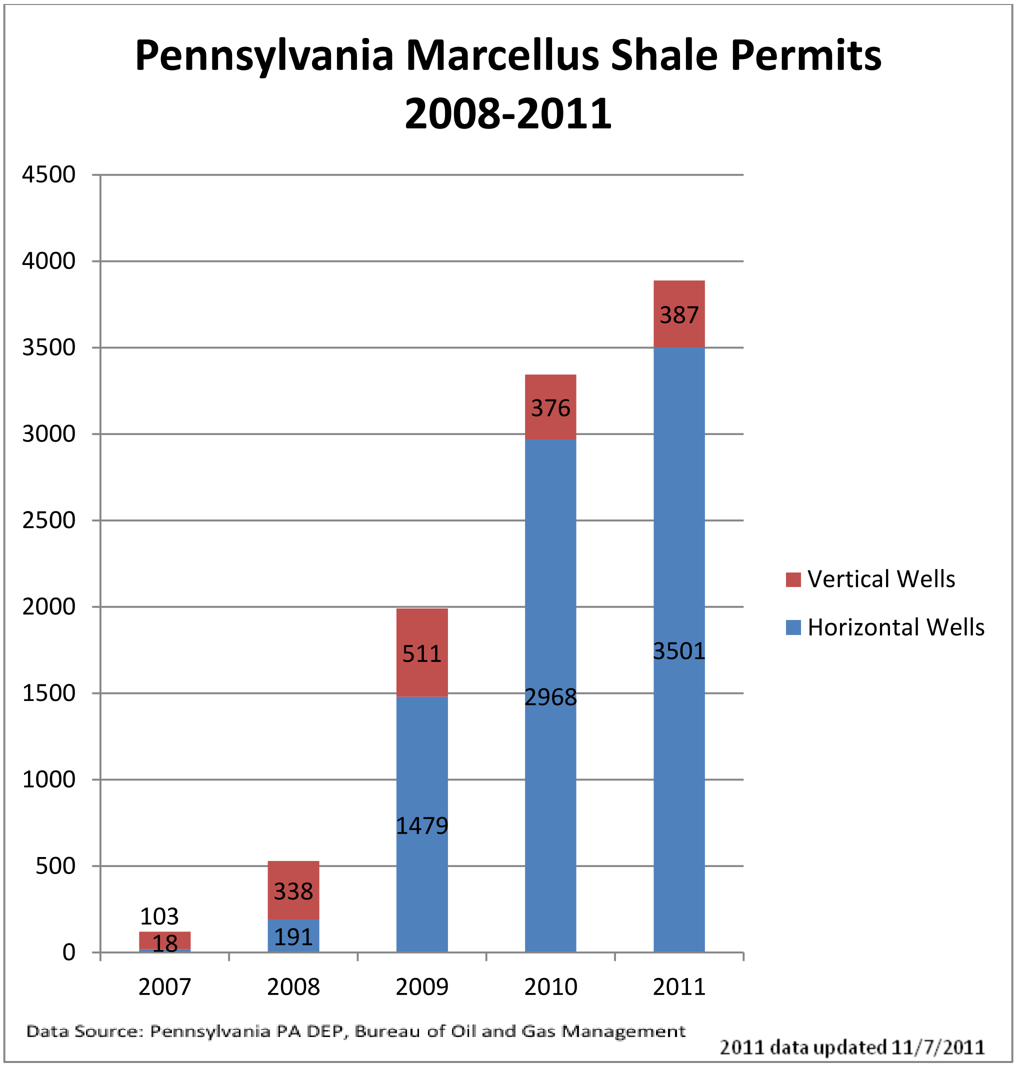

Figure 33: Pennsylvania Horizontal vs. Vertical Well Permits

Figure 33 shows the number of horizontal and vertical well permits issued by Pennsylvania DEP for the years 2007 to 2011. This graph shows a dramatic increase in permits in general, as well as an increase in horizontal drilling permits. In 2007, there were one hundred and twenty one total permits issued, with only eighteen being horizontal well permits. In 2011, there were 3,888 total permits, with 3,501 being horizontal wells. This represents a shift from 14.9 percent horizontal permits in 2007 to 90.0 percent horizontal permits in 2011. Since 2008 the number of vertical wells has remained relatively stagnant. This increase might be due to the difference in production rates between vertical and horizontal wells. The unique issues related to horizontal drilling need to be further studied as the practice of horizontal drilling continues to grow.

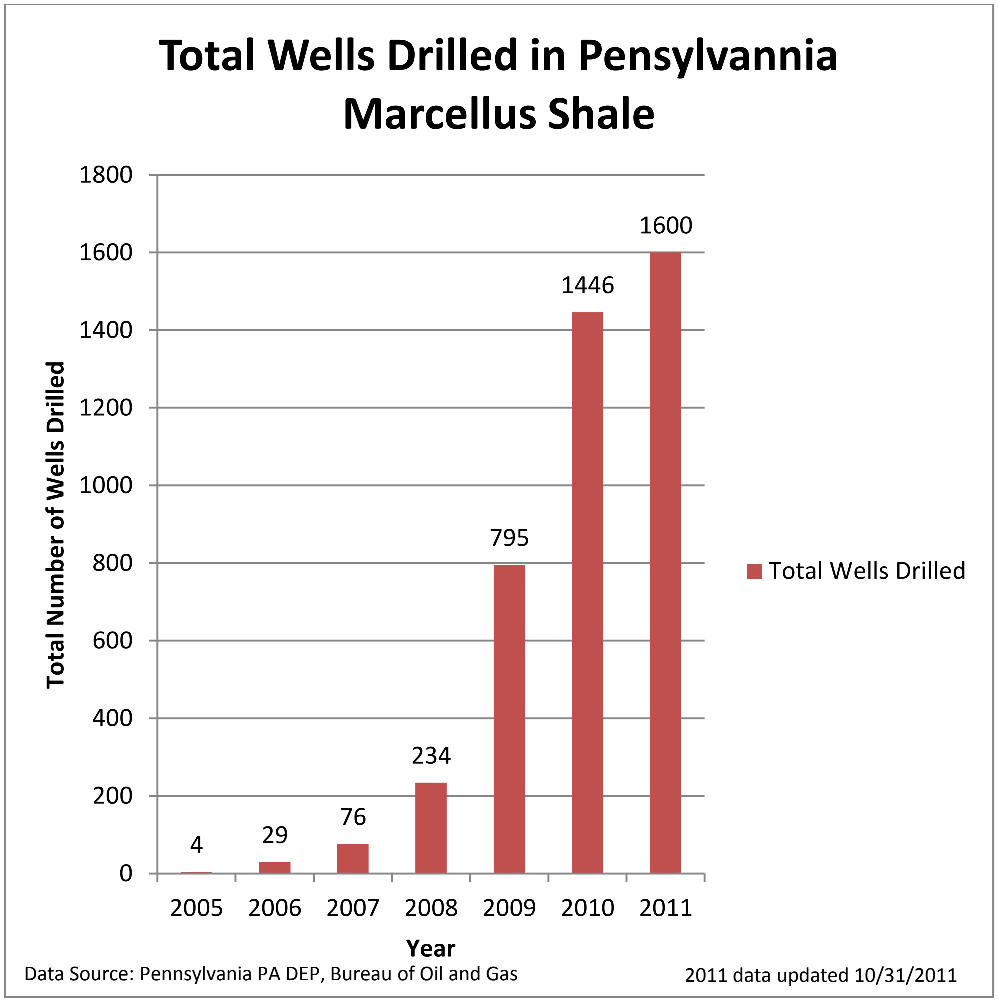

Figure 34: Pennsylvania Total Wells Drilled

Figure 34 shows the number of natural gas wells drilled in Pennsylvania's Marcellus Shale from 2007 to 2011. It can be seen that there is a dramatic increase in drilling since 2005. In 2005 there were only four wells drilled in Pennsylvania's Marcellus Shale. Only six years later, in 2011, there were 3,600 wells drilled. This is due to the fact that, in 2005, Range Resources drilled the first few exploratory wells in Pennsylvania's Marcellus Shale. They found these wells to be productive and the exploitation of the Marcellus Shale began. A large number of companies followed suit and started to buy leases and drill wells at an extraordinary rate.

5.2 Company Analysis

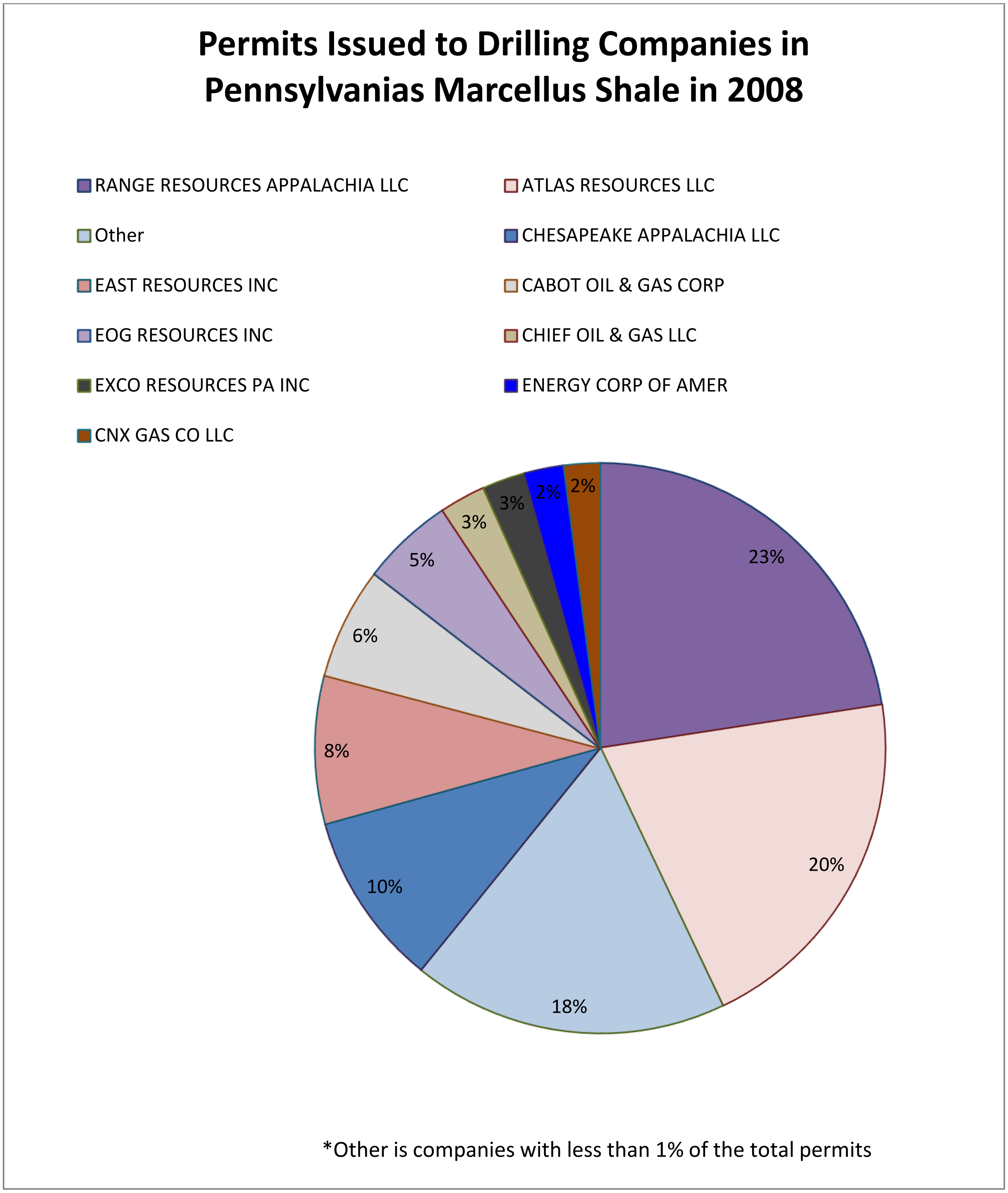

Figure 35: Pennsylvania Permits Issued in 2008

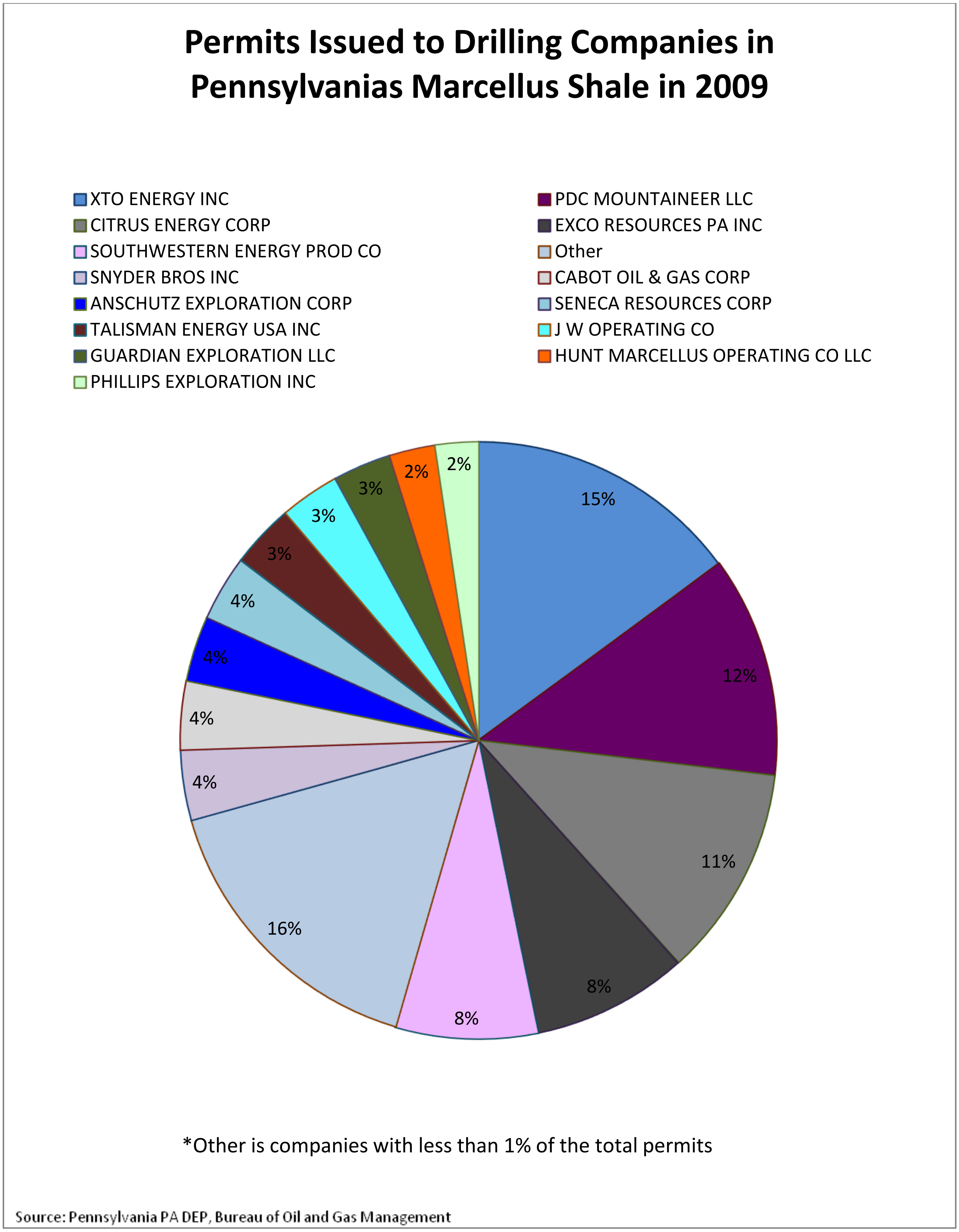

Figure 36: Pennsylvania Permits Issued in 2009

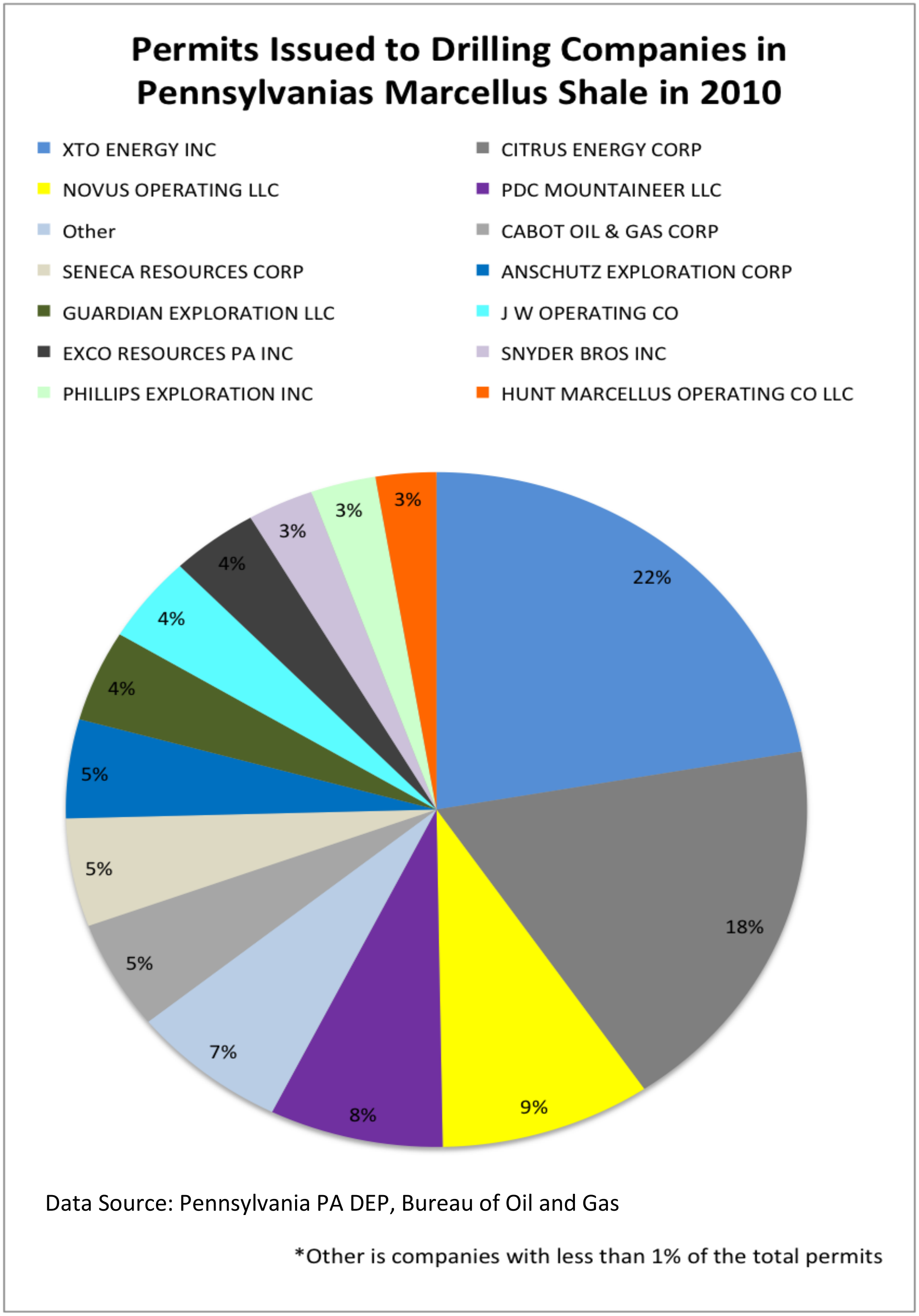

Figure 37: Pennsylvania Permits Issued in 2010

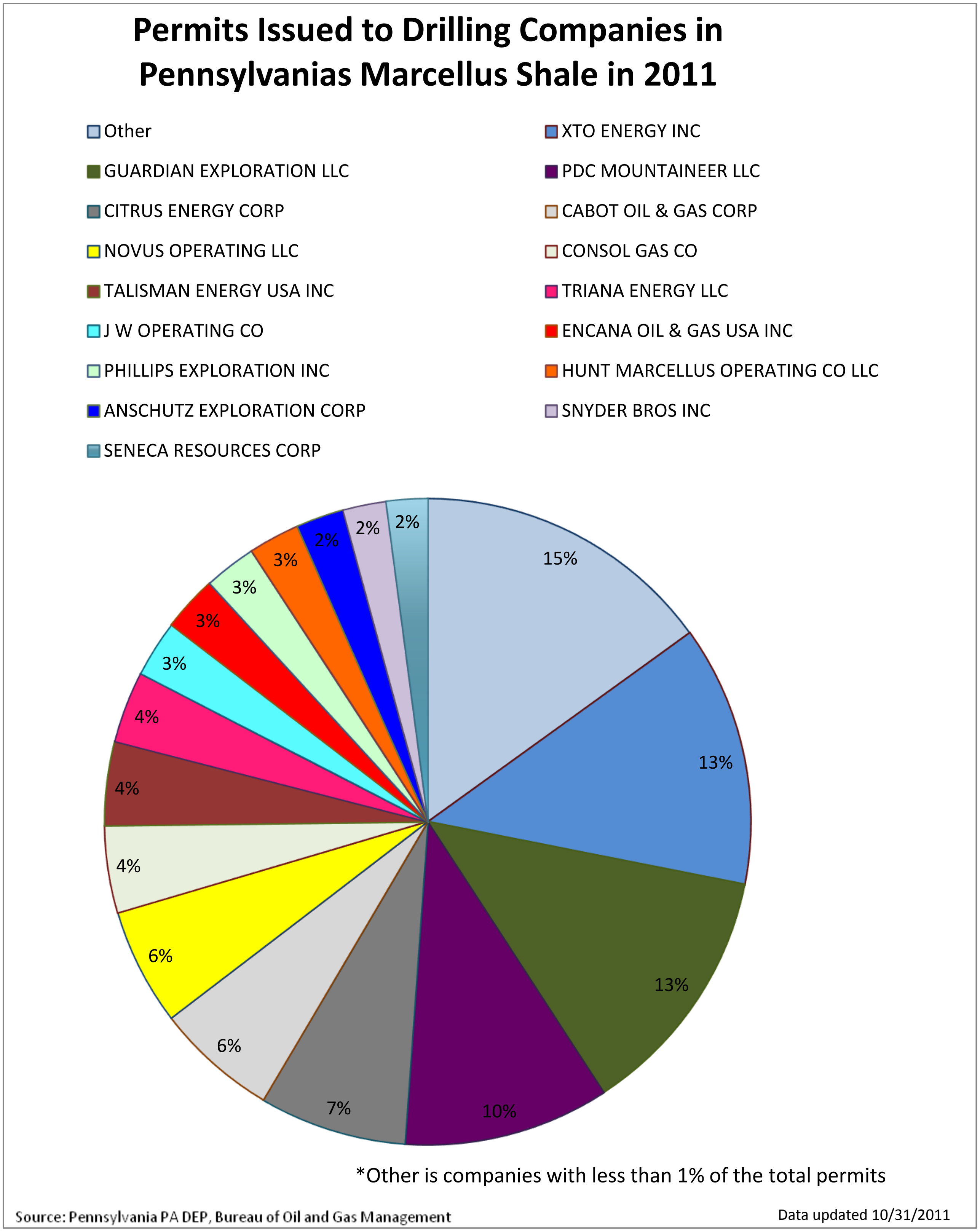

Figure 38: Pennsylvania Permits Issued in 2011

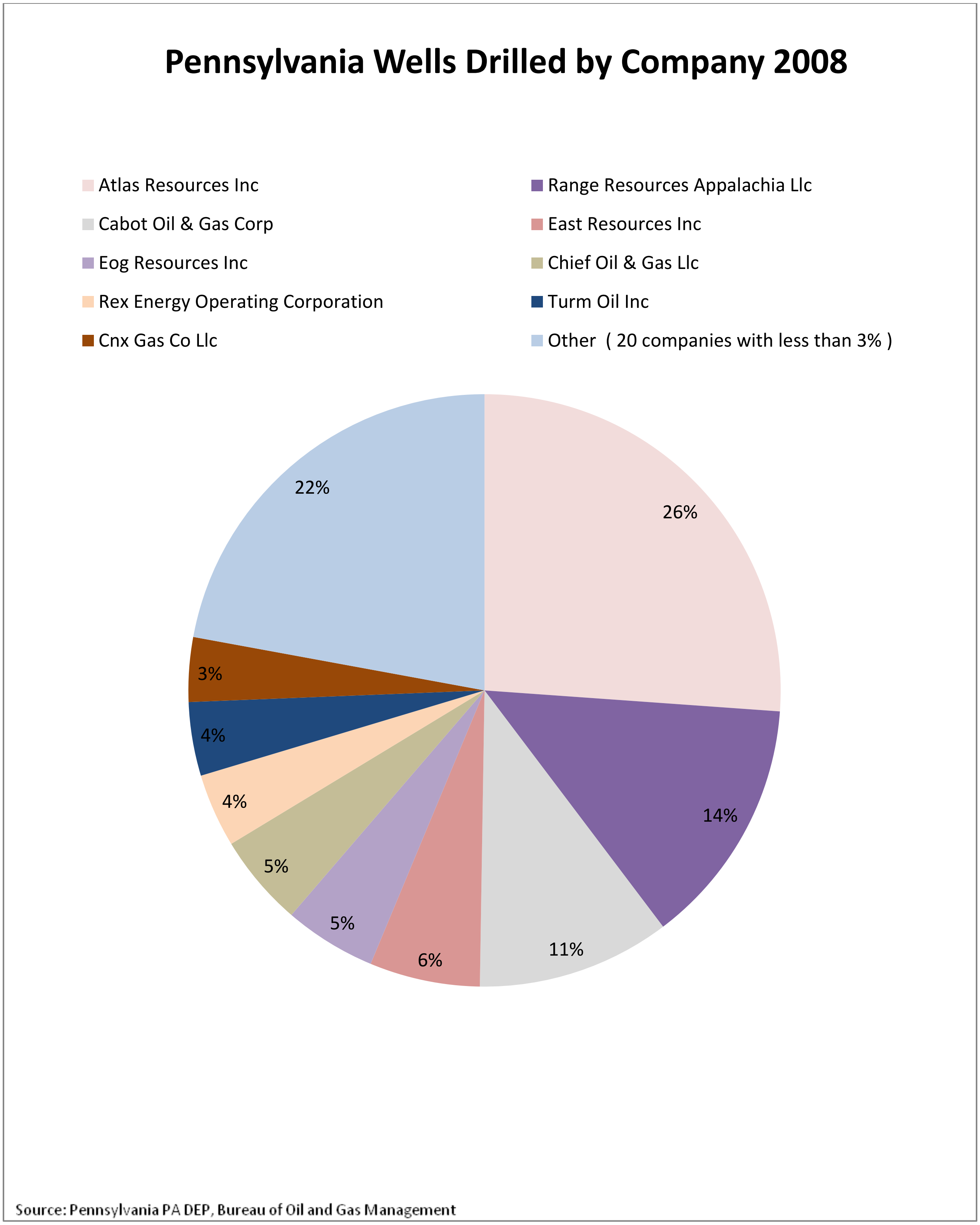

Figure 39: Pennsylvania Wells Drilled in 2008

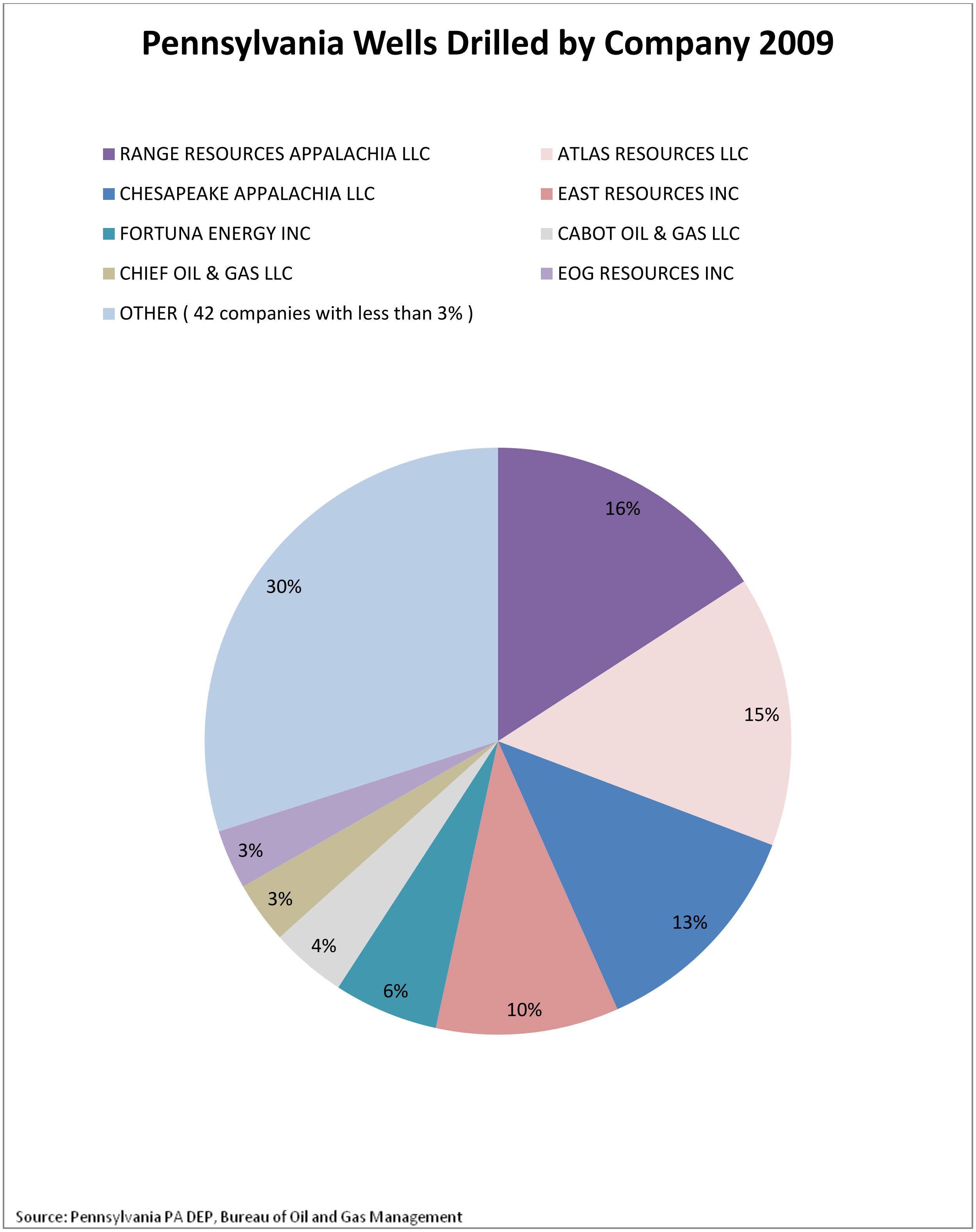

Figure 40: Pennsylvania Wells Drilled in 2009

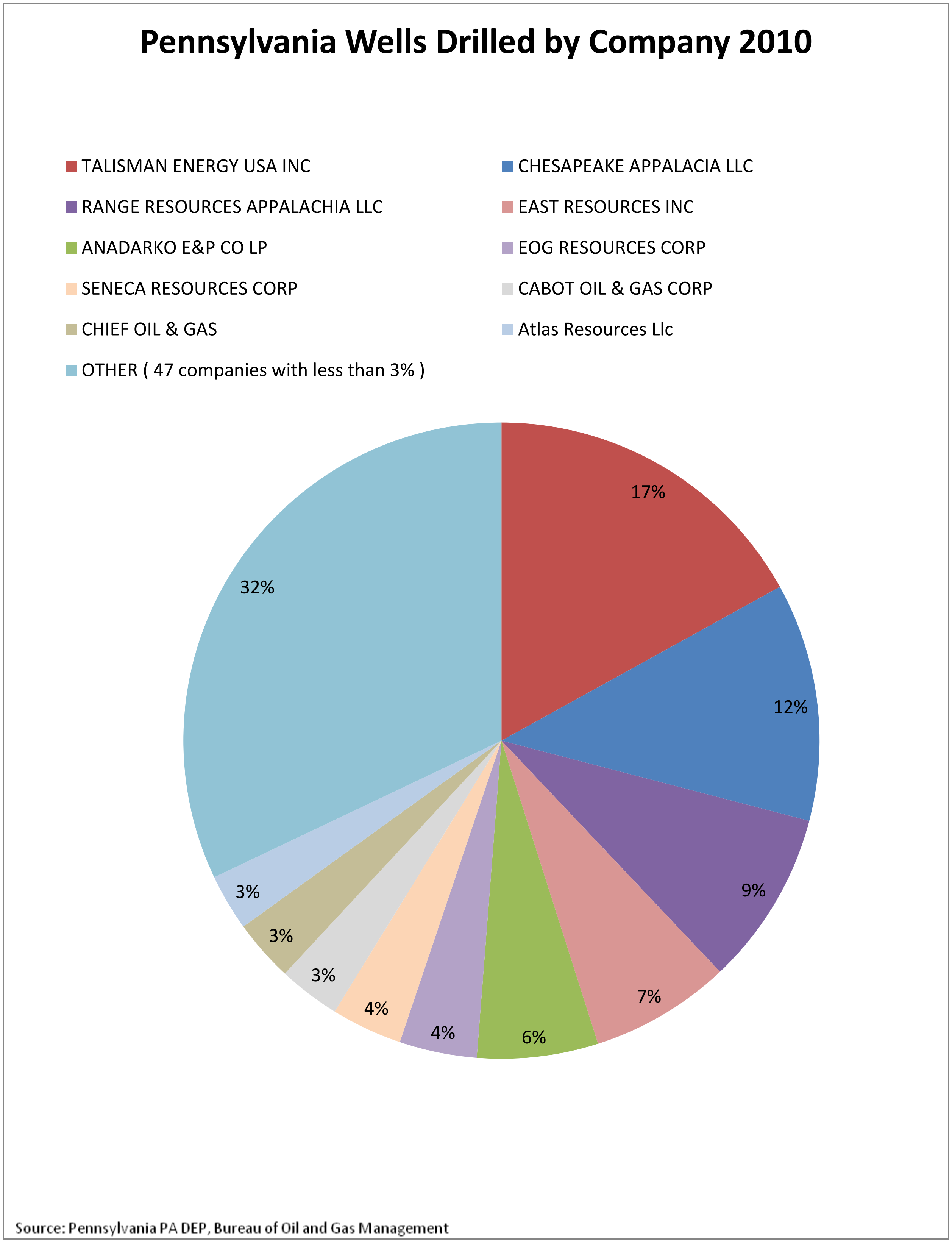

Figure 41: Pennsylvania Wells Drilled in 2010

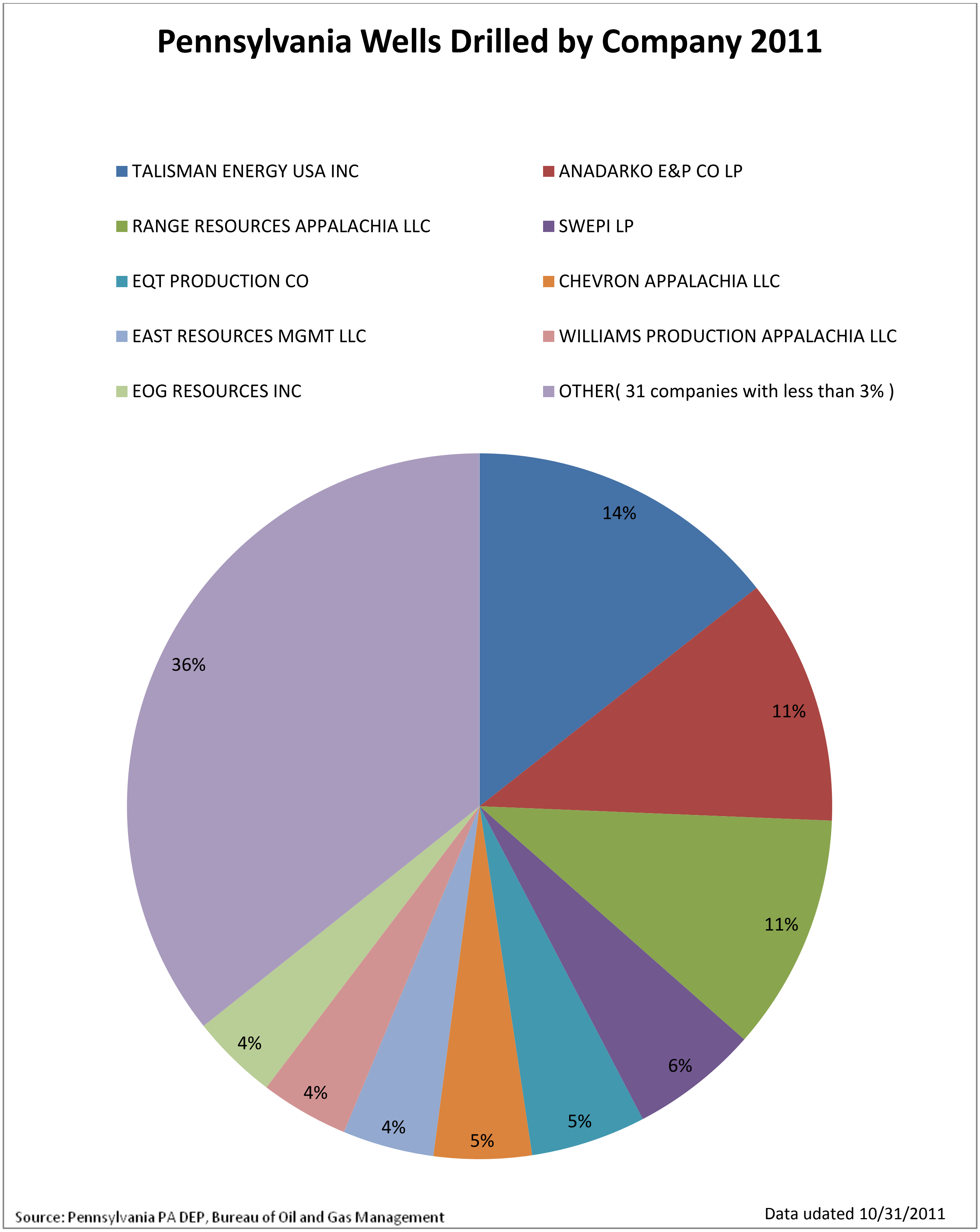

Figure 42: Pennsylvania Wells Drilled in 2011

Figures 35 through 42 show permit ownership, by company, in pie chart form. Each pie chart corresponds to a different year, with the years 2008-2011 represented. In the year 2008 (Figure 35), the companies that secured the most permits were Range Resources, Atlas Resources, Chesapeake Appalachia, East Resources, and Cabot Oil and Gas with twenty three, twenty, ten, eight, and six percent respectively. For 2009 (Figure 36), companies with the most permits were XTO Energy, PDC Mountaineer, Citrus Energy, Exco Resources, and Southwestern Energy Production with fifteen, twelve, eleven, eight, and eight percent respectively. In the year 2010 (Figure 37), greatest permit ownership belonged to XTO Energy, Citrus Energy, and Novus Operating with twenty two, eighteen, and nine percent of total permits respectively. In 2011 (Figure 38), companies with the greatest permit ownership were XTO Energy, Guardian Exploration, and PDC Mountaineer with thirteen, thirteen, and ten percent of the total permits respectively.

Permits do not necessarily always equate to wells drilled. For this reason, Figures 39-42 depict wells drilled, by company, in the years 2008-2011. In the year 2008, companies that drilled the most wells included Atlas Resources, Range Resources, Cabot Oil and Gas, and East Resources with twenty six, fourteen, eleven, and six percent of the total drilled wells respectively. In 2009, Range Resources, Chesapeake Appalachia, and East resources drilled the most wells with fifteen, fifteen, thirteen, and ten percent of the total wells drilled respectively. For the year 2010, Talisman Energy USA, Chesapeake Appalachia, Range Resources, and East Resources had the biggest share of total wells drilled with seventeen, twelve, nine, and seven percent respectively. Finally, in the year 2011, Talisman Energy USA, Anadarko E&P, Range Resources, and Swepi LP had the largest share of total wells drilled with fourteen, eleven, eleven, and six percent respectively.

Figures 35-42 show the relationship between permits and wells drilled. As mentioned earlier, the number of permits far exceeds the number of wells actually drilled. Due to the fact that permits and leases last for significantly longer than just a year, a permit may be secured and only acted upon one or more years later. For this reason, permit acquisition can serve as a leading indicator of drilling patterns by company. One example in the graphs is Chesapeake Appalachia. During 2008, this company secured ten percent of the permits but drilled less than three percent of the total wells drilled that year. The following year, Chesapeake drilled thirteen percent of the wells. The fact that drilling activity appears to slightly lag permitting activity has important implications. This should be considered by regulators as well as by institutions and individuals who are studying the industry. Recommendations and best practices should be tailored to current violators and those purchasing the majority of permits because these will be the major players in the next couple of years.

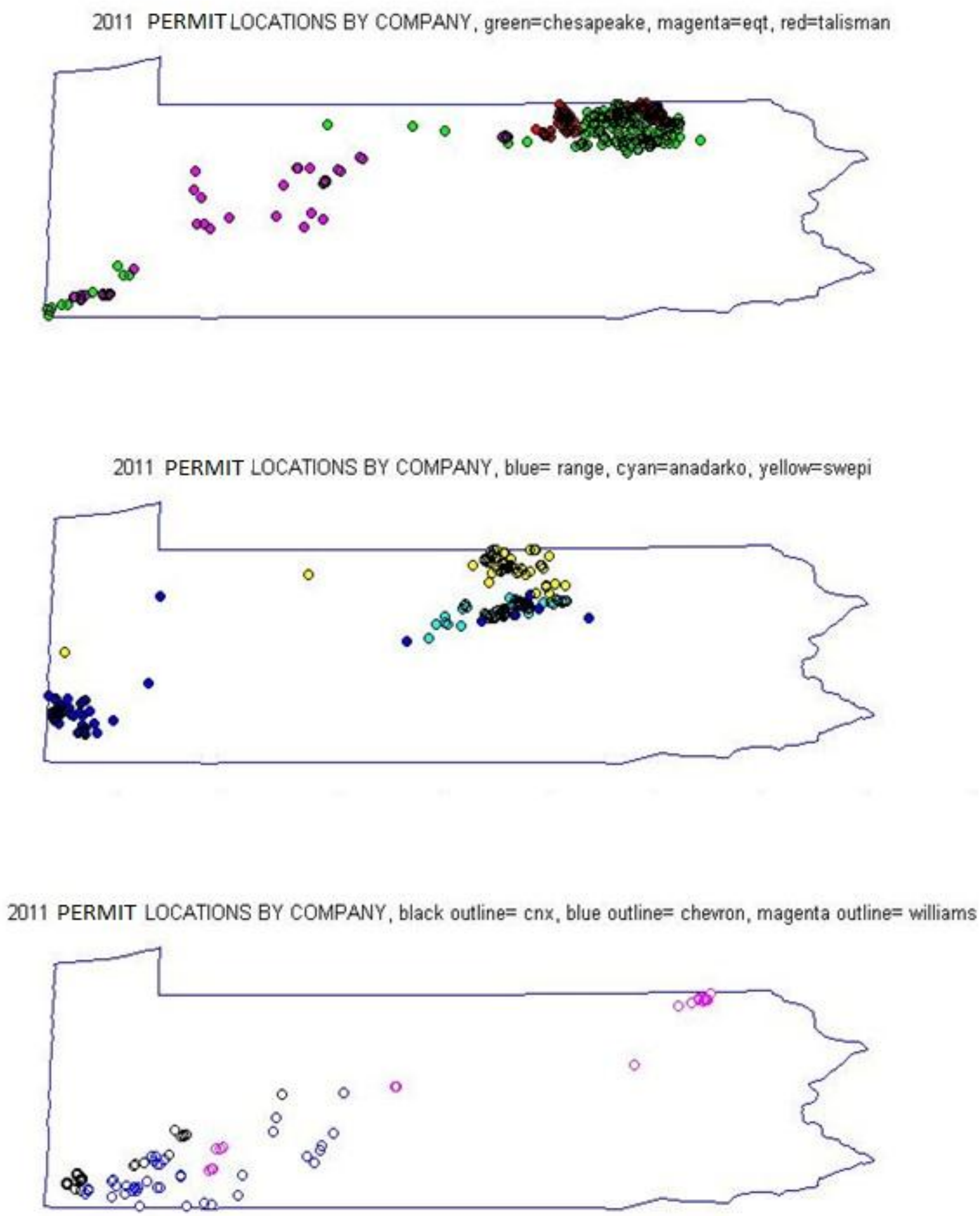

Figure 43: Pennsylvania Permit Locations By Company

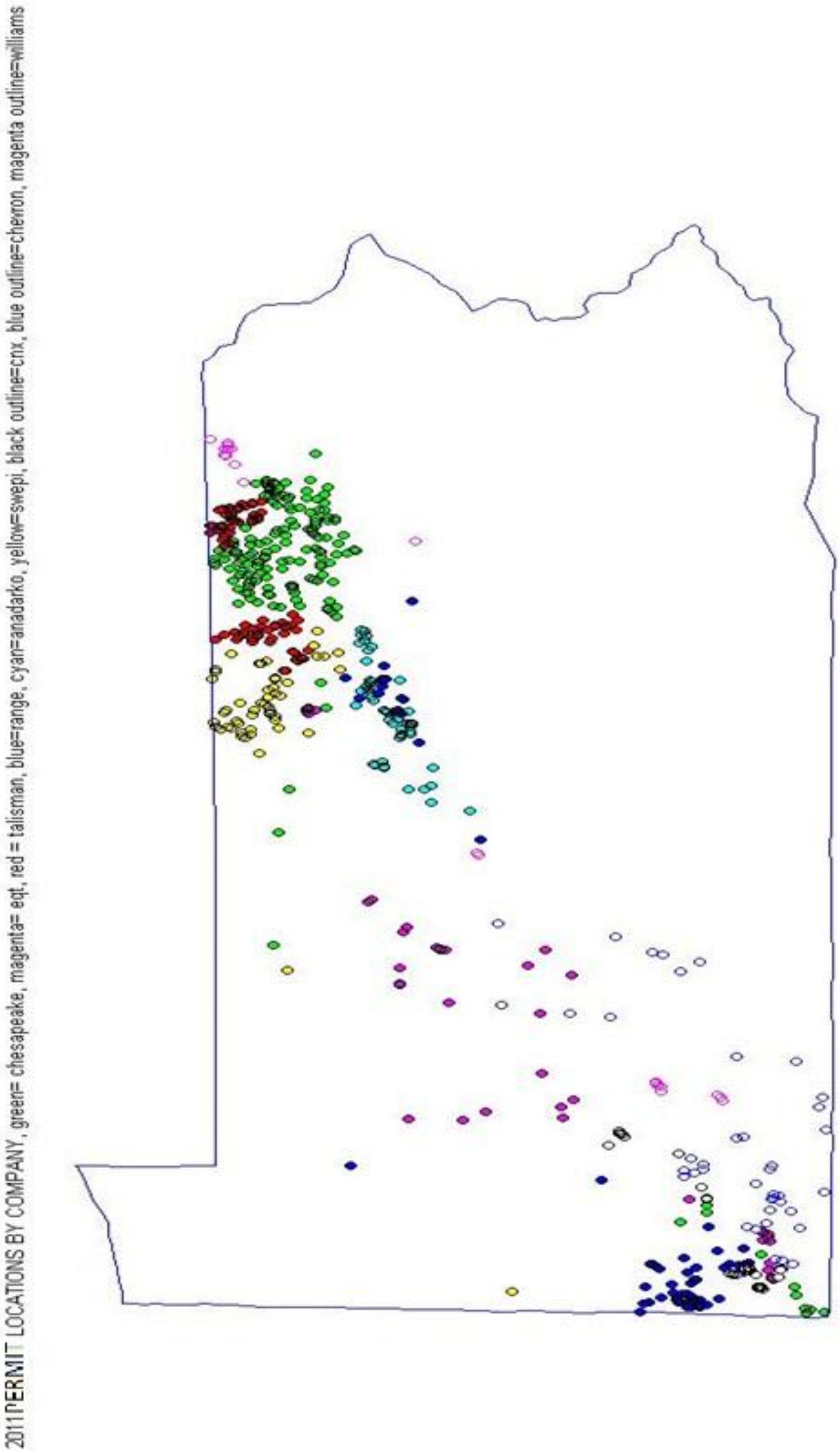

Figure 44: Pennsylvania Permit Locations by Company (Combined)

Figure 43 and 44 show the permit locations of nine of the key drilling companies in 2011. Figure 43 shows the locations of the nine companies with three companies to each graph for easier visibility. Figure 44 shows the same nine companies all displayed on the same map. The nine companies include Chesapeake Appalachia, EQT Production, Talisman Energy USA, Range Resources, Anadarko E&P, Swepi LP, CNX Gas, Chevron Appalachia, and Williams Production Appalachia. These companies were selected to be included either because of their high amount of permits or because of their violation activity.

From both maps, it is evident that companies lease land and secure permits in regions in clusters. For example, Range Resources, the company we visited for our site visit, has permits primarily in the southwestern portion of the state. Companies adhere to this pattern for a variety of reasons. As we learned on our site visit, a company is more inclined to cluster their wells in a certain region partially because they can take advantage of the infrastructure they already have assembled in that region. Equipment is more easily moved between Range drilling sites because they are so close together. Antennas set up in the vicinity of the well pad, that are used to isolate a specific location in the well underground using electromagnetic technology, can be reused if they are in close enough proximity to other drilling sites.

As is evident by Figures 43 and 44, drilling companies do tend to cluster their permits and this has important implications for the rest of our results. This needs to be considered when looking at clusters of violations. While clusters of violations may indicate some geological challenges unique to a specific region, they may also simply reflect on the specific company that drills primarily in that area. Certain procedural factors for that specific company may play more of a role in an increased incidence of certain violations than geology, but this needs to be verified by further research.

5.3 General Violation Analysis

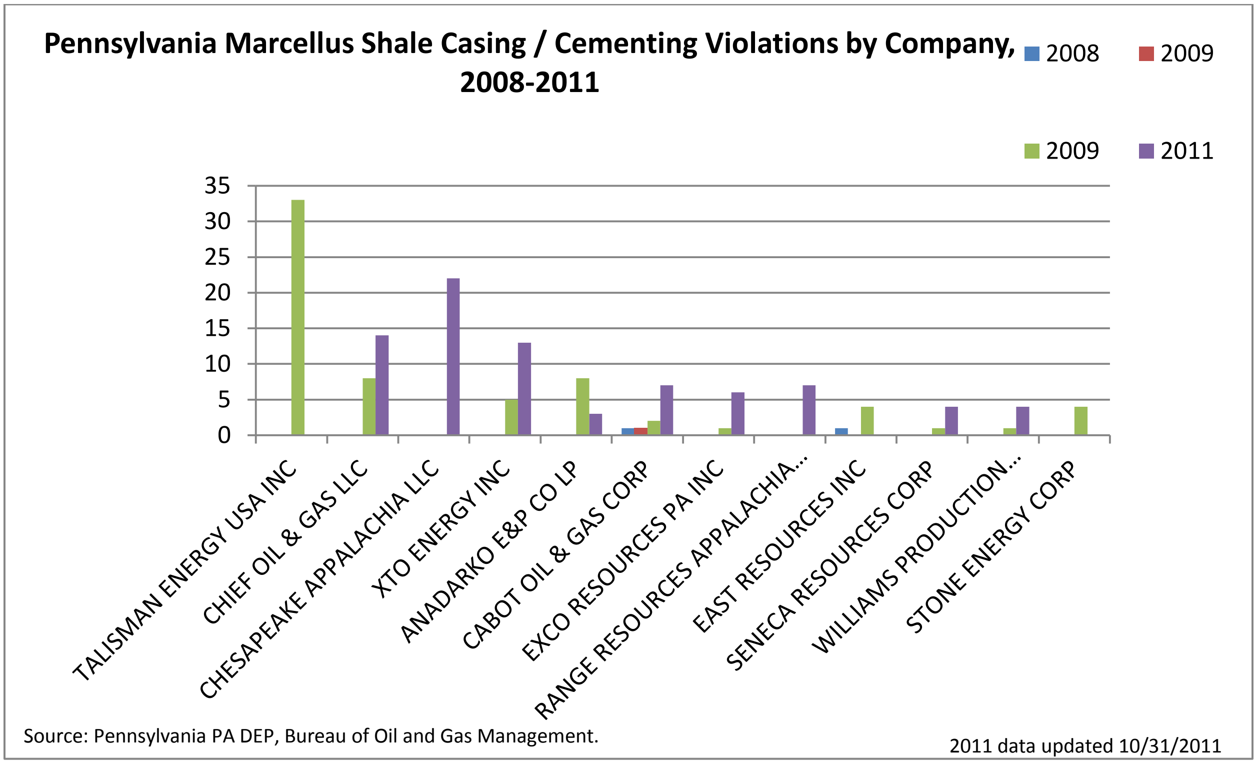

Figure 45: Pennsylvania Violations by Company

Figure 45 shows the amount of well casing and cementing violations committed by certain companies in the years 2008 through 2011. Talisman Energy USA began drilling in the Marcellus Shale in 2010 and was cited for 33 cementing and well casing violations that year. In 2011, Talisman continued to drill but was not cited for any well casing and cementing violations. This drastic decrease in violations could possibly be due to a change in Talisman's drilling practices after becoming accustomed to the unique aspects of the Marcellus Shale. Chesapeake Appalachia was also cited for violations in only one year. In 2011, Chesapeake was cited for 22 cementing and well casing violations after having no cementing and well casing violations recorded in previous years. More research is required to identify the cause of this sudden increase.

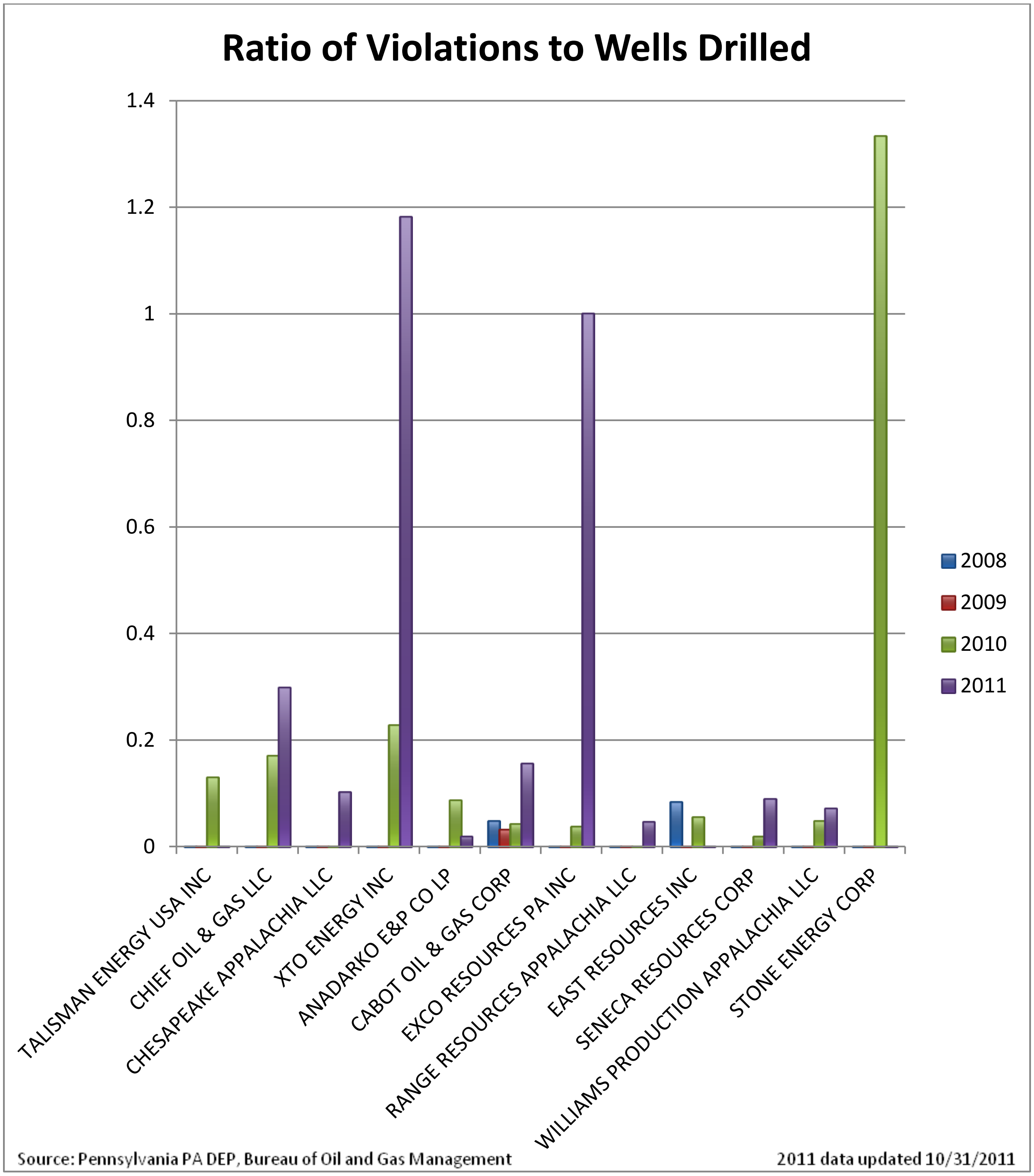

Figure 46: Pennsylvania Violations per Well

Figure 46 shows the ratio of cementing and well casing violations to total wells drilled for many companies that are active in the Marcellus Shale. Some companies, such as Stone Energy Corporation, showed a high number of violations relative to the amount of wells that they drilled. In contrast, other companies, such as Range Resources, had a very small number of violations in comparison to the amount of wells they drilled. In interviews with Range Resources personnel, it was apparent that Range took precautions above just the bare minimum legal requirement to avoid violations. This could possibly explain their above average violation record.

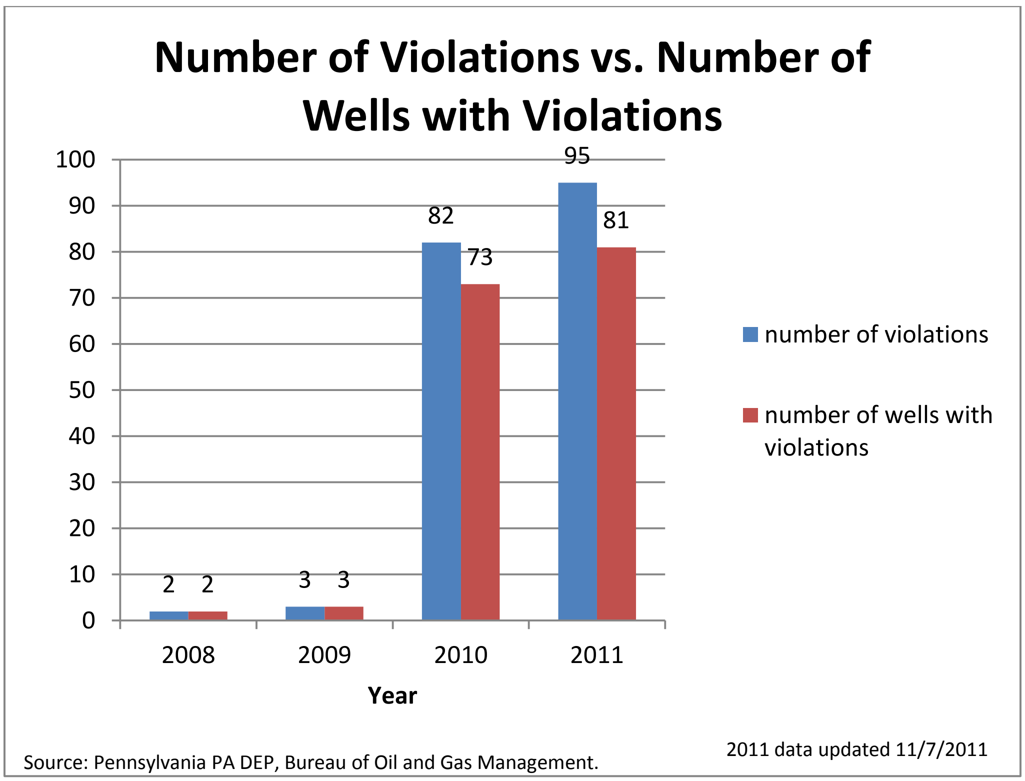

Figure 47: Pennsylvania Violations vs. Number of Wells with Violations

Figure 47 illustrates the amount of well casing and cementing violations and the number of wells with these violations. This graph also shows that wells can be issued have multiple violations. The graph shows that there is a significant increase in violations in 2010. This could be from an increase in staffing of inspectors, an increased in interest of the well's casing and cementing, or an increase in regulations pertaining to well casing and cementing. More research is required to describe the trends in this graph.

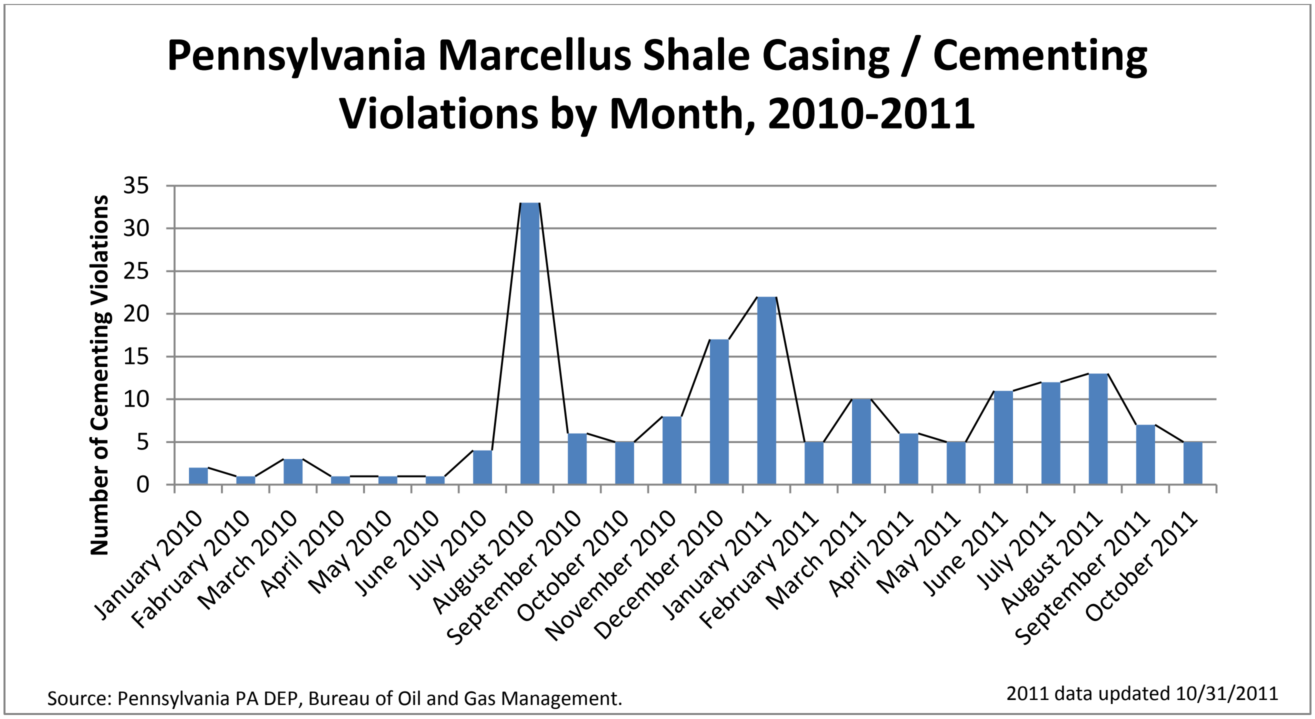

Figure 48: Pennsylvania Cementing and Well Casing Violations by Month

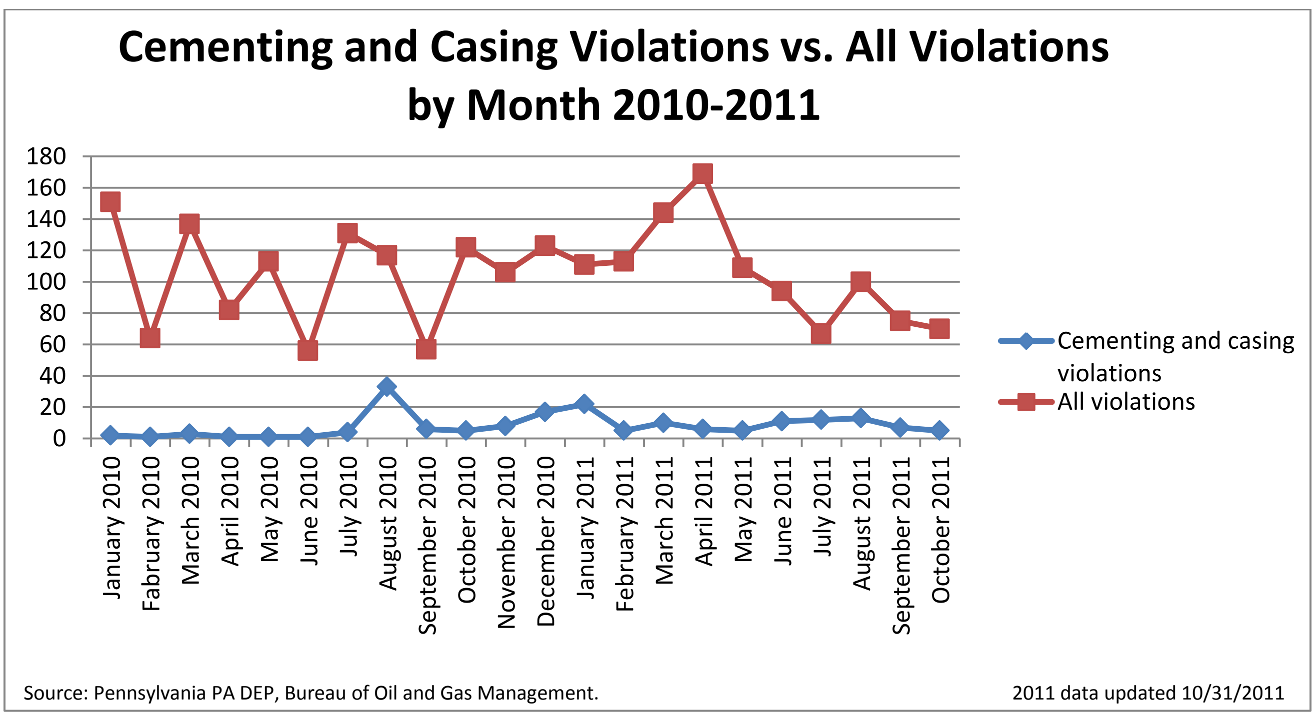

Figure 49: Pennsylvania Violations by Month

Figure 48 shows the number cementing and well casing violations issued by month. Figure 49 shows both the number of cementing and well casing violations and the number of total violations issued by month. The number of cementing and well casing violations does not appear to directly correlate to the number of total violations. That said, both the cementing and well casing violations and the total violations share some peak months. Certain months, especially August 2010, have abnormally high amounts of cementing and well casing violations. According to Mike Makin of Range Resources, drilling companies operate year round and do not encounter seasonal drilling issues. Professor Anthony Ingraffea of Cornell University raised a contrasting point of view. He suggested that, during the colder months, the factor of human error may be more likely to come into play. Yet this theory doesn't explain why a warm summer month like August would have such a high number of violations. This issue requires further investigation in order to determine the definitive cause of these monthly fluctuations.

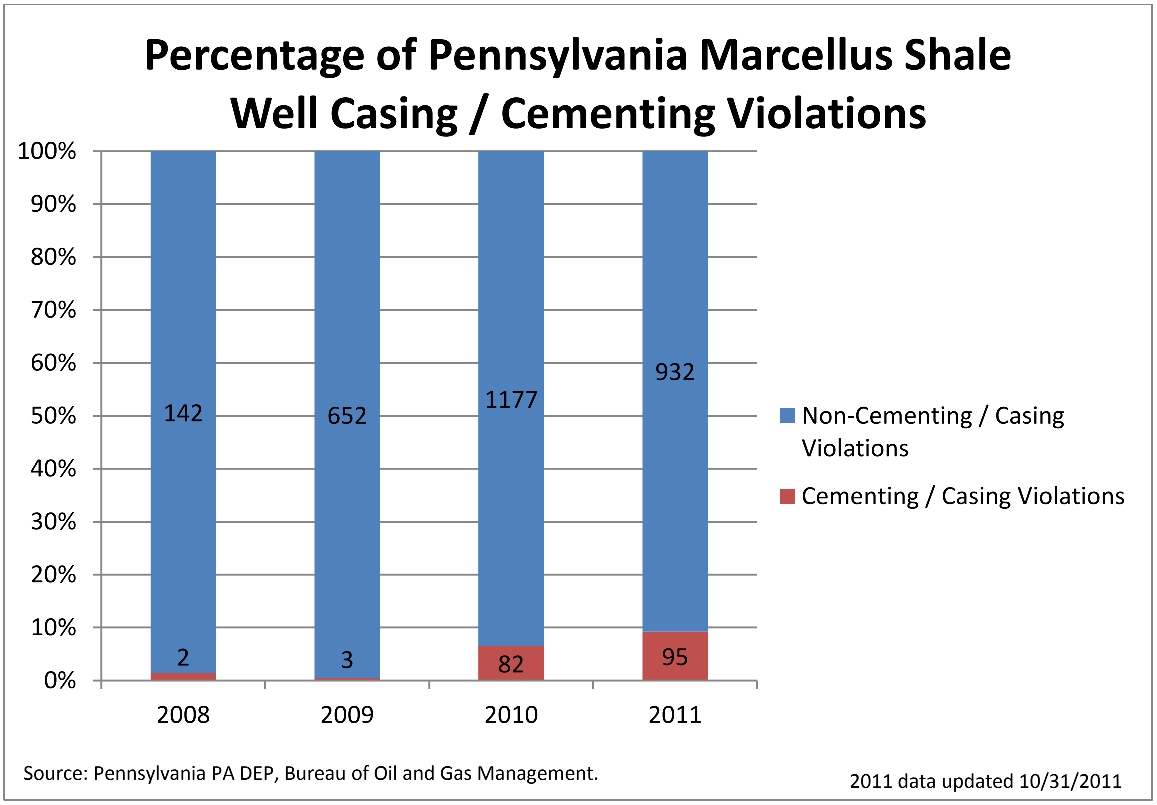

Figure 50: Percentage of Well Casing and Cementing Violations

Figure 50 shows the number of cementing and well casing violations as a percentage of Pennsylvania's total drilling violations for the years of 2008 through 2011. The number of cementing and well casing violations, as well as the number of total violations, experienced significant growth in 2010. In 2011, the amount of well casing and cementing violations continued to grow. This trend coincides with the increase of drilling activities each year. The steep rise in well casing and cementing violations between 2009 and 2010 could be due to an increase in state regulatory efforts. An expansion of the inspector staff and a more detailed inspection process could cause a higher number of violations to be recorded. Further research into the cause of the large increase from 2009 to 2010 could provide significant insights into the inspection process and violation rates have evolved.

5.4 Specific Violations Analysis

Violation Code	Description	Legal Citation	Regulation Descrption
207B	Failure to case and cement to prevent migrations into fresh groundwater	58 P.S. 207(b)	State Statute
78.83GRNDWTR	Improper casing to protect fresh groundwater	58 P.S. 207(b); 25 Pa. Code 78.81(c); 78.83(b-f)	State Statute
78.83COALCSG	Improper coal protective casing and cementing procedures	25 Pa. Code 78.83(g-h)	State Regulation
78.85	Inadequate, insufficient, and/or improperly installed cement	25 Pa. Code 78.85; 78.83(d); 78.81(c); 207; 78.401(a)(2)	State Regulation
78.84	Insufficient casing strength, thickness, and installation equipment	25 Pa. Code 78.84	State Regulation
209CASING	Using inadequate casing	58 P.S. 209, 25 Pa. Code 78.71, 78.84, 79.12	State Statute
78.81	Failure to case and cement properly through storage reservoir or storage horizon	25 Pa. Code 78.81(d)(2)	State Regulation
79.12	Inadequate casing/cementing in conservation well	25 Pa. Code 79.12	State Regulation
78.73A	Operator shall prevent gas and other fluids from lower formations from entering fresh groundwater.		
78.73B	Excessive casing seat pressure	25 Pa. Code 78.73(b)	State Regulation
209BOP	Inadequate or improperly installed BOP, other safety devices, or no certified BOP operator	58 P.S. 209, 25 Pa. Code 78.72, 79.12	State Statute
78.81D2PLAN	Failure to obtain proper approval for casing and cementing procedure for wells in storage and protective areas	25 Pa. Code 78.81(d)(2)	State Regulation
78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days	25 Pa. Code 78.86	State Regulation

Table 5: Violation Codes

Table 4 depicts all cementing and well casing violations defined by Pennsylvania state law. All of the above described violations are very important, but some can result in more serious environmental and public health consequences than others. According to Scott Perry, of the Pennsylvania DEP, violations which result in the migration of methane are considered to be the most serious. These are followed, in order of decreasing severity, by violations which result in a public health issue, violations which cause environmental harm, and paperwork violations. The distribution of these violations for the years 2008 through 2011 is shown in Figure 51.

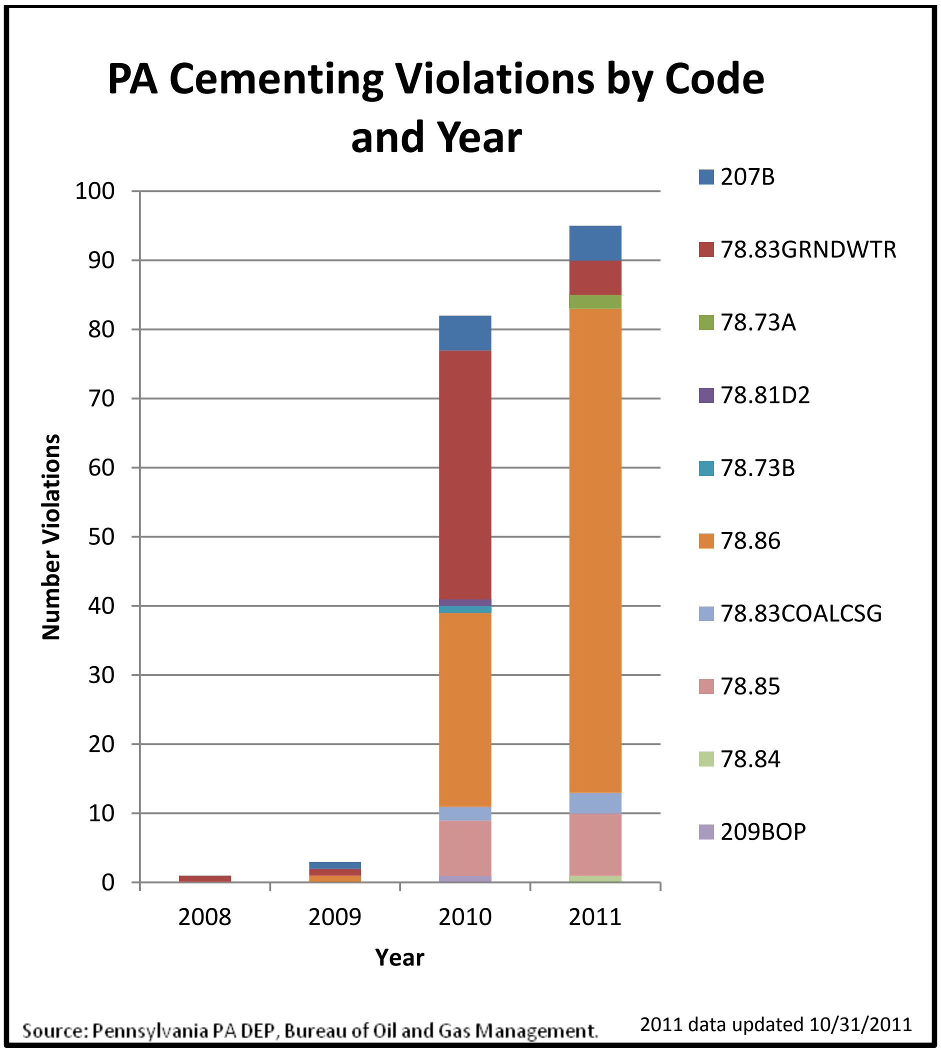

Figure 51: Pennsylvania Well Casing and Cementing Violation Distribution

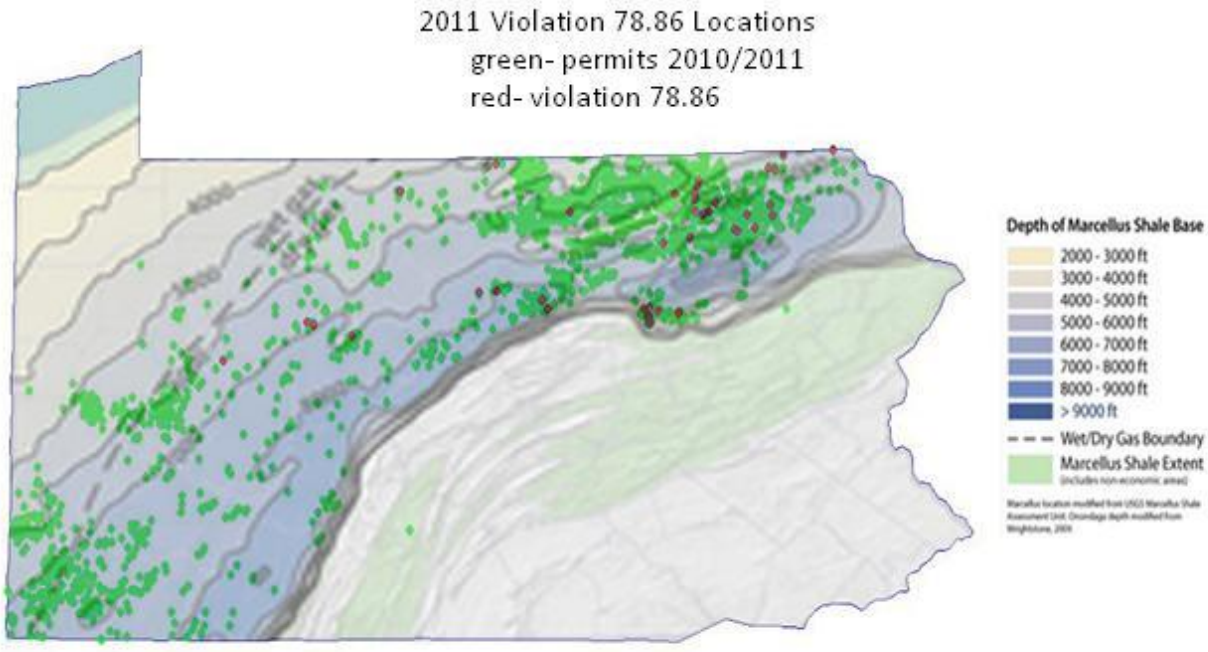

Figure 52: Pennsylvania Distribution of 78.86 Violations in 2011

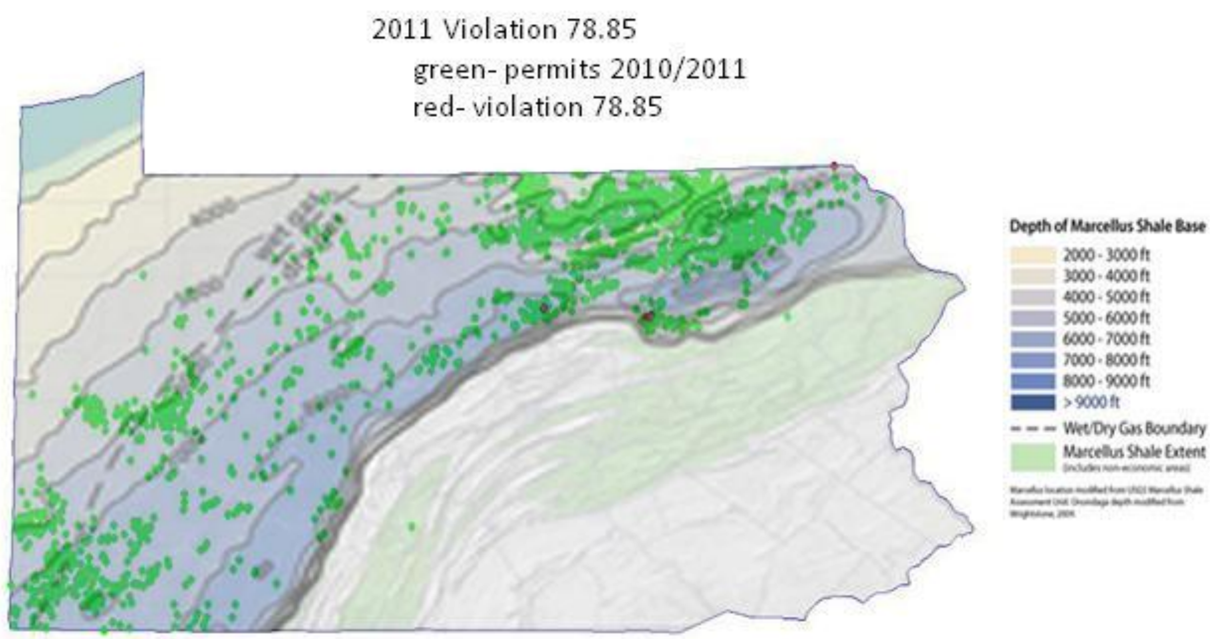

Figure 53: Pennsylvania Distribution of 78.85 Violations 2011

Figures 52 and 53 show the locations of 2010 and 2011 drilling permits in green. As in Figure 32, the latitude and longitude information used to generate this plot came from the Pennsylvania state permitting records. The permit numbers associated with all incidents of violation 78.86 (“failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days”) and 78.85 (“inadequate casing/cementing in conservation well”) were paired with latitude and longitude coordinates for those wells in the permit data. Violations 78.86 and 78.85 are shown in red on Figure 52 and Figure 53 respectively.

From the maps, it is clear that there are certain regions where there are very few violations and other areas where there are many. Wells in southwest Pennsylvania are fairly densely populated but there are no violations. The bulk of violations are located in the northeast and north-central parts of the state. This could be due to several different aspects. The higher frequency of violations in this region could reflect more stringent inspections rather than an actual increase in unsafe cementing and well casing practices. Higher population density in this part of the state may drive the state and inspectors to pay more attention to safety in this particular region. An additional cause could be unique geological features in the regions were the clusters are observed. Some of these regions are known to have shallower gas containing formations. Problems like channeling and tunneling in cement in these areas could lead to the higher rate of occurrence of cementing and well casing violations in these regions.

6. Findings and Implications

Based on the data analysis, interviews, and site visit our group identified several key conclusions that could help to advance the safety and sustainability of shale gas extraction in the Marcellus Shale. These conclusions include recommendations and areas for further research. Conclusions touch on all aspects of the drilling process from design to completion and even data management, with a special focus on cementing and well casing. Our findings are organized into three broader areas of focus: inspections, violations, and data.

6.1 Inspections

Many of our findings and subsequent questions are related to the inspection process and the nature of the inspector workforce. Background research, data analysis, interviews, and the Range Resources site visit all pointed towards the importance of maintaining a strong and well distributed team of inspectors. Both permitting activity and drilling activity are increasing rapidly in the state of Pennsylvania as shown in Figure 31 and Figure 34. In order to ensure that there are a sufficient amount of inspectors in comparison to the number of wells, the inspector workforce may need to be increased. Maintaining an ample amount of inspection resources is incredibly important to ensure safe drilling operations. Another important factor to consider is the distribution of the inspector workforce. Some of the violation trends observed by the group might be partially explained by the distribution of the inspector workforce. For instance, Figure 52, which shows clusters of Pennsylvania violation 78.86 in 2011, and Figure 53, which shows clusters of Pennsylvania violation 78.85 in 2011, might be partially explained if inspectors are found to be more densely populated in the regions containing clusters. Diligent inspection plays an important role in encouraging companies to foster safe drilling practices. For this reason, understanding exactly how the inspector workforce is structured and distributed throughout the state is crucial to ultimately maximizing safety.

6.2 Violations

In the data analysis section of this project, our group found numerous trends described in the results and analysis section. These trends point towards some broader implications, raise additional questions, and highlight areas for further research. One of the key findings in the violation data was the vast difference in violation rates and patterns between different drilling companies. There is evidence that indicates some companies appear to be doing considerably better than others at keeping cementing and well casing violation rates low. This is especially evident in Figure 46, which showed the ratio of violations per well for different companies, as well as in Figure 45, which displays the number of cementing and well casing violations for different companies from 2008 through 2011. These figures show that Range Resources has among the lowest cementing and well casing violation rates. On our site visit with Range, we observed some of the additional precautions they take on site to ensure safety. Range includes an extra layer of cement in addition to the layers required by law. Further study of companies with low violation rates, such as Range, could aid in identifying procedural factors that make the whole process safer. Likewise, examining companies with the worst violation ratios could lead to a better understanding of the reasons why violations occur.

Our second significant observation has to do with violation clusters in specific regions and their potential causes and implications. These clusters were apparent in Figure 52, which shows the locations of violation 78.86 in the year 2011, and Figure 53, which shows the locations of violation 78.85 in the year 2011. While our group has some ideas as to why this might be occurring, more research needs to be done to uncover the definitive cause of these clusters. On November eighth, at the United States Energy Association's Marcellus Shale conference, Pennsylvania's Acting Deputy Secretary of Oil and Gas Management, Scott Perry, noted the different geological challenges that might occur in certain regions with shallower gas bearing formations. This idea was reinforced in an interview with Professor Anthony Ingraffea of Cornell University. According to Professor Ingraffea, when drilling through shallower gas containing formations, channeling can occur in the cement due to the release of gas from these outside formations. These unique geological challenges may account for the clusters of violations in the northeast and north-central regions. One other potential explanation ties into our findings in Figures 43 and 44, which demonstrate the fact that different drilling companies tend to secure most of their permits in distinct and separate regions. As a result of these permitting patterns, the clusters of violations in certain regions may be due to the practices of the specific companies that operate there, rather than geological factors. Regardless, more research needs to be done to determine the source of these clusters so that the root causes can be identified and addressed to ensure safety.

6.3 Data

One of the largest components of this project was analyzing public violation data to uncover relevant trends and patterns. The data contained enough information and was sufficiently robust to conduct some useful analysis. However, the group encountered some challenges associated with the structure, presentation, and nature of the data provided. Based upon this experience, the group has formulated several recommendations to improve the usability of the public data from Pennsylvania.

A few minor changes in Pennsylvania's violation data spreadsheets could potentially make the systems more user friendly. In the state of Pennsylvania, the inclusion of both violations and enforcements in the same data sheet was a substantial source of confusion for the group. Separating enforcements and violations into two different spreadsheets might make the data easier to use. Another way to address this issue would be to create a simple user key containing general information about the inspection process and what constitutes a violation or enforcement. This would be a small change that could greatly increase the usability and accessibility of the violation data. In addition, the inclusion of a query based search feature similar to the one implemented by West Virginia would help make the data easier to manipulate. In the future, it would be ideal for all Marcellus states to either compile a unified database of violations or work together to better harmonize their data. This would enable people to examine the data for broader trends. When violation patterns are more completely assessed, changes can be made to make natural gas production in the Marcellus Shale a safer process.

6.4 Summary

All of the previous conclusions are focused on one common goal: improving the safety of the shale gas extraction industry. The inspection process is crucial to keeping companies in compliance with current safety and environmental regulations. Improvements in the inspection process as well as in the number and distribution of inspectors throughout the state will help promote safe and sustainable drilling practices. An improvement in the data management system will allow for better analysis of the violation data, which may help inspectors better focus their efforts. As the shale gas industry continues to grow, improvements in the inspection process, data analysis, and data management will allow for the continued development of safe and sustainable drilling practices.

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Appendix A: The DOE Sponsor Description

The DOE is a division of the United States Government created in 1977 under President Jimmy Carter and is responsible for policies and regulations regarding energy and nuclear materials (Fernald Closure Project, 2007). The Secretary of Energy, a political appointee of the President of the United States, is responsible for the control and supervision of the Department. The current United States Secretary of Energy is Dr. Steven Chu (United States Department of Energy, 2011). Under the Secretary of Energy, another political appointee of the President, the Deputy Secretary of Energy, is tasked with assisting the Secretary of Energy, and if necessary, assuming his responsibilities in the case of absence. The next level of management consists of three Under Secretaries of Energy, also appointed by the President. The Under Secretaries manage the major areas of the department's work. Below the Under Secretaries, the President also appoints eight Assistant Secretaries of Energy whose duties are assigned by the Secretary of Energy. In addition, the annual budget is about $29 Billion coming from the federal government with roughly 16,000 federal employees (Office of Chief Financial Officer, 2011).

The DOE is broken down into more than 13 different offices (United States Department of Energy, 2011). The specific office we have been assigned to work with, the Office of Policy and International Affairs, is headed by Assistant Secretary of Energy David Sandalow. The Office of Policy and International Affairs is tasked with managing and coordinating policy and governing the international activities of the DOE. Currently, Assistant Secretary Sandalow has five Deputy Assistant Secretaries working under him to assist him with the various undertakings of the Policy and International Affairs office.

Appendix B: IQP Qualifications

It is expected that students completing the Interactive Qualifying Project address "a problem that lies at the intersection of science or technology with social issues and human needs" (WPI, 2006, Chapter 2: Objectives of the IQP). This project focuses on the need for an investigation into the violations associated with cementing and well casing related to shale gas drilling. The science portion of the project focuses on the technical aspect of identifying problems associated with the cementing and well casings that can allow the possible migration of methane and other contaminants outside of the wellbore. Drinking water has been contaminated with methane and potentially by drilling fluids laced with chemicals that have migrated outward as a result of a leak in the well casing. Therefore, the drilling occurring in the Marcellus Shale play and violations concerning well cementing can and will affect human health and safety if left unchecked. This subject has major economic implications that could heavily affect the American economy by creating jobs and revenue flows that drilling activities generate. Also, the production of domestic natural gas supplies can improve the energy security of the United States by potentially constraining the availability of future supplies of shale gas.

Also, this game changing energy source (i.e., shale gas) could have major political and economic ramifications. Every state with shale gas ready for extraction has a vested interest in using their resources to bring income into the state. representatives in the United States federal government to help push the government towards allowing more drilling of the Marcellus shale while also demanding safe and sustainable industry operations that protect human health and the environment. As a result, this is becoming a major issue for the presidential election in 2012. In addition, this issue has an impact on society as the communities affected by the drilling are putting their safety at risk. Our IQP will allow us to question the ethics of drilling into the Marcellus shale and make recommendations to the DOE based upon our research that are both technical and societal.

Appendix C: Pennsylvania Well Permit Application

5500-PM-OG0001 Rev. 10/2009

pennsylvania
DEPARTMENT OF ENVIRONMENTAL PROTECTION

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL PROTECTION
OIL & GAS MANAGEMENT PROGRAM

DEP USE ONLY	
AUTH #	
Check #	Amount $

PERMIT APPLICATION FOR DRILLING OR ALTERING A WELL

DEP USE ONLY			
Notes	OGO #	Objection Date - Do not issue before:	Well Permit #
	Bond #		Special Cond. A B C D E F
	C: G:	Date Approved:	Watershed Name:
	INV:		Designation: HQ EV

Please read instructions before you begin filling in this form.

Applicant (Operator) Name	DEP Client ID#	Phone	FAX	Check if new address. ☐
Mailing Address (Street or PO Box)	City / State		Zip +4	Country (if not USA)

(Well) Farm Name	Well #	Serial #
County	Municipality	Project # (from DEP)

If you are applying for a permit to redrill, drill deeper, or alter a well that was previously permitted or registered, ***or for a well site that was previously permitted but not drilled***, check this box ☐ and enter the permit or registration number here:

If applying for a permit to rework an existing well not registered or permitted, check this box ☐ and **enter date drilled**, if known:__________________ (see instructions)

PNDI Attached: ☐ Any "hit" must include accepted mitigation plan from applicable agency.

PERMIT TYPE
Check applicable.
Application is to:
- ☐ Drill a new well
- ☐ Deepen a well
- ☐ Redrill a well
- ☐ Alter a well
- ☐ E&S Control Module
- ☐ Other (specify)

TYPE OF WELL
Check one.
- ☐ Gas
- ☐ Oil
- ☐ Comb. (gas & oil)
- ☐ Injection, recovery
- ☐ Injection, disposal
- ☐ Coalbed Methane
- ☐ Gas Storage
- ☐ Other (specify)

APPLICATION FEE
Check applicable.
- ☐ Marcellus Well: Non-Vertical
- ☐ Marcellus Well: Vertical
- ☐ Non-Marcellus Well: Non-Vertical
- ☐ Non-Marcellus Well: Vertical
- ☐ $200 (Home Use Well)
- ☐ $500 E&S Fee
- ☐ $ 0 (Rehab orphan)
- ☐ Vertical: Length_____ ft.
- ☐ Marcellus: Length_________ ft.
- ☐ Non-Vertical: Length _______ ft.

Total Application Fee $ _______

COORDINATION WITH REGULATIONS AND OTHER PERMITS	Yes	No
1. Will the well be subject to the **Oil and Gas Conservation Law**? If "No," go to 2).	☐	☐
a. If "Yes" to #1, is the well at least 330 feet from outside lease or unit boundary?	☐	☐
b. Does the location fall within an area covered by a spacing order?	☐	☐
2. Will the well penetrate a **workable coal seam**? If "No," include justification and supporting documentation.	☐	☐
3. If the well will penetrate a **workable coal seam**, and the well is a "non-conservation" gas well, does the location comply with the distance requirements of Section 7 of the Coal and Gas Resource Coordination Act? (At least 1,000 feet from all existing wells).	☐	☐
a. If "No," is the required exception request attached? (Check here if re-working an existing well: ☐ N/A)	☐	☐
4. Will the well be drilled at a location where the **coal** has been removed?	☐	☐
5. Will the well be drilled through an **active (operating or projected) coalmine**, or within 1,000 feet of the boundary?	☐	☐
a. If "Yes," print the names of: Mine: Operator:		
6. Will the well penetrate or be within 2,000 feet of an active **gas storage reservoir** boundary?	☐	☐
a. If Yes, print the names of: Storage Field: Operator:		
7. Is the proposed well location within the permitted area of a **landfill**?	☐	☐
8. Will the well site be within 100 feet (measured horizontally) of a **stream, spring or body of water** identified on the most current 7½' topographic map?	☐	☐
a. If "Yes," is a request for a waiver (form 5500-FM-OG0057), and E&S control plan attached?	☐	☐
9. Will the well site be within 100 feet of a **wetland** or in a **wetland**?	☐	☐
a. Is the well site within 100 feet of a wetland greater than one acre in size?	☐	☐
If yes, is a waiver request (form 5500-FM-OG0057) and E&S control plan attached?	☐	☐
10. Will the well be drilled within 200 feet (horizontally) from any existing **building** or an existing **water supply**?	☐	☐
a. If "Yes," is written consent from the owner attached?	☐	☐
b. If written consent is not attached, is a variance request (form 5500-FM-OG0058) attached?	☐	☐

DEP USE ONLY
Date Stamps/Notes
Auth ___________
Site ___________
Clnt ___________
APS ___________
Acct ___________

	Yes	No
11. Will the well be located where it may impact a public resource as outlined in the "**Coordination of a Well Location with Public Resources**" form 5500-PM-OG0076? If yes, attach a competed copy of the form.	☐	☐
12. Is the well site in a **Special Protection** High Quality (HQ) or Exceptional Value (EV) watershed?	☐	☐
13. Is this well part of a development where you need an **Earth Disturbance Permit** for Oil and Gas Activities disturbing more than 5 acres? If yes, attach a completed Erosion Sediment and Stormwater Control Module or list the number and date of the ESCGP-1 Approval. ______________________	☐	☐

Signature of Applicant	The person signing this form attests that they have the authority to submit this application on behalf of the applicant, and that the information, including all related submissions, is true and accurate to the best of their knowledge.	
Signature of Person Authorized to Submit Application	*(Print or Type)* Name of Signer: Title:	Date
Application Preparer/Contact:	Phone:	

5500-PM-OG0001 Rev. 10/2009

pennsylvania
DEPARTMENT OF ENVIRONMENTAL PROTECTION

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL PROTECTION
OIL & GAS MANAGEMENT PROGRAM

Farm Name - Well #	
Applicant Name	DEP ID#
DEP USE ONLY	APS #

PERMIT APPLICATION FOR DRILLING OR ALTERING A WELL

Page 2 --- Record of Notification / Written Consent

List the following: surface landowner, all landowners or water purveyors whose water supplies are within 1,000 feet of this proposed well location; gas storage operator if within 2000 feet; all coal owners and lessees of all underlying workable coal seams; operators of underground coal mines at the proposed location; and coal operators with a deep mine within 1,000 feet. Mark the boxes, "X," which show the parties' interests. Use additional forms if you need more space. You are required to notify each of these parties.

		Surface Landowner	Coal Owner	Coal Lessee	Coal Mine Operator	Gas Storage Operator	Within 1,000 feet: Surf Owner with Water	Within 1,000 feet: Water Purveyor	Within 1,000 feet: Coal Mine Operator	Notification (Note the means and attach proof.) Certified Mail Dates: Sent	Certified Mail Dates: Return Receipt	Address Affidavit	Written Consent
Name:	Address:												
Name:	Address:												
Name:	Address:												
Name:	Address:												
Name:	Address:												
Name:	Address:												
Name:	Address:												

Optional: **Signature below indicates the party's approval of the well location, and waives the 15-day objection period.** Check applicable box.				Signature below indicates written consent. Check applicable box.	
☐ Water Purveyor or ☐ Landowner with water supply within 1,000 ft.	Date	Coal ☐ Operator, ☐ Owner, or ☐ Lessee	Date	Owner of: ☐ water supply, or ☐ building within 200 feet	Date
☐ Water Purveyor or ☐ Landowner with water supply within 1,000 ft.	Date	Coal ☐ Operator, ☐ Owner, or ☐ Lessee	Date	Address (of above)	
☐ Water Purveyor or ☐ Landowner with water supply within 1,000 ft.	Date	Coal ☐ Operator, ☐ Owner, or ☐ Lessee	Date		
☐ Water Purveyor or ☐ Landowner with water supply within 1,000 ft.	Date	Coal ☐ Operator, ☐ Owner, or ☐ Lessee	Date	Owner of: ☐ water supply, or ☐ building within 200 feet	Date
Surface Landowner at proposed location	Date	Coal Operator within 1,000 feet of proposed location	Date	Address (of above)	
Surface Landowner at proposed location	Date	Gas Storage Operator within 2,000 feet	Date		

Appendix D: Amendment to Pennsylvania Rules and Regulations

RULES AND REGULATIONS

Title 25—ENVIRONMENTAL PROTECTION

ENVIRONMENTAL QUALITY BOARD

[25 PA. CODE CH. 78]

Oil and Gas Wells

[39 Pa.B. 6232]
[Saturday, October 24, 2009]

The Environmental Quality Board (Board) by this order amends Chapter 78 (relating to Oil and Gas Wells) by adding new definitions and amending § 78.19 (relating to permit application fee schedule) as set forth in Annex A. The Board has the authority to establish fees, by regulation, under section 201 of the Oil and Gas Act (act) (58 P. S. § 601.201). Under this provision, the Board has the authority to set fees at an amount that bears a reasonable relationship to the cost of administering the act.

This order was adopted by the Board at its meeting of July 21, 2009.

A. *Effective Date*

These amendments will go into effect upon publication in the *Pennsylvania Bulletin* as final-form rulemaking.

B. *Contact Persons*

For further information contact Ronald Gilius, Director, Bureau of Oil and Gas Management, Rachel Carson State Office Building, 5th Floor, 400 Market Street, P. O. Box 8765, Harrisburg, PA 17105-8461, (717) 772-2199 or Scott Perry, Assistant Counsel, Bureau of Regulatory Counsel, P. O. Box 8464, Rachel Carson State Office Building, Harrisburg, PA 17105-8464, (717) 787-7060. Persons with a disability may use the Pennsylvania AT&T Relay Service by calling (800) 654-5984 (TDD users) or (800) 654-5988 (voice users). This final-form rulemaking is available on the Department of Environmental Protection's (Department) web site: www.depweb.state.pa.us.

C. *Statutory Authority*

The final-form rulemaking is adopted under the authority of section 201(d) of the act which authorizes the Department to establish, by regulation, well permit fees that bear a reasonable relationship to the cost of administering the act, section 604 of the act (58 P. S. § 601.604) which directs the Board to adopt regulations necessary to implement the act, and section 1920-A of The Administrative Code of 1929 (71 P. S. § 510-20), authorizing and directing the Board to adopt regulations necessary for the performance of the work of the Department.

D. *Background and Purpose*

The act was passed on December 19, 1984, and established a $100 fee for oil and gas well permits. Section 201(d) of the act allows the Department to increase the fee by regulation. Under this provision, fees must be set at a level that "bears a reasonable relationship to the cost of administering" the act. Fees for traditional oil and gas wells have never been increased. However, fees for Marcellus Shale wells were recently increased on April 18, 2009.

At the same meeting that the Board approved the proposed rulemaking that is made final by this order, the Board also approved a final-omit rulemaking that increased permit fees for wells that produce natural gas from the Marcellus Shale formation. The proposed rulemaking also included the new Marcellus Shale permit application fees that were included in the final-omitted rulemaking to allow interested persons to comment on the new Marcellus Shale permit application fees as part of the proposed rulemaking. The Board committed to making appropriate changes to the Marcellus Shale permit application fees as part of the proposed rulemaking in response to public comments. On April 18, 2009, the final-omitted regulations increasing permit fees for Marcellus Shale wells were published in the *Pennsylvania Bulletin* and became final. See, 39 Pa.B. 1982.

There are three considerations that support a regulation that increases the permit application fees authorized by the act. First, the costs of administering the act have increased significantly since 1984 when the General Assembly established the $100 fee that the Department currently charges. This $100 per permit application fee does not currently bear a reasonable relationship to the cost of administering the act. Indeed, in 2008 permit fees only provided 15% of the revenue needed by the Department to administer the act. The remaining 85% was provided through the General Fund.

Second, the number of permit applications that the Department reviews annually has grown dramatically over the past several years. In 2000, 1,354 wells were drilled in this Commonwealth. In 2008, the Department issued 7,927 well permits, of which 7,451 were for traditional oil and gas wells. The Department's current staffing levels for the Oil and Gas Program were established at a time when the Department reviewed considerably fewer permit applications than it reviews today. To properly review the number of applications that the Department currently receives and to inspect the operations at sites that currently posses a permit, the Department needs additional staff that the current $100 fee cannot support.

Finally, there continues to be significant interest in the development and recovery of natural gas resources from the Marcellus Shale formation that underlies much of this Commonwealth. Despite the recent economic downturn and the decline of natural gas prices, Marcellus Shale well permitting and drilling is increasing. In 2008, the Department permitted 476 Marcellus Shale wells. In the first 5 months of 2009, the Department permitted 569 Marcellus Shale wells.

The drilling and completion techniques that allow recovery of natural gas from the Marcellus Shale present new and expanded environmental considerations that the Department must evaluate to ensure the gas is recovered in an environmentally protective manner. Many of the environmental considerations are directly related to the use of water to recover natural gas from the Marcellus Shale formation. Extracting natural gas from the Marcellus Shale requires a process known as "hydraulic fracturing." Hydraulically fracturing the Marcellus Shale uses far greater amounts of water than traditional natural gas exploration. Large volumes of water are pumped into the formation, along with sand and other materials under high pressure, to fracture the rock surrounding the well bore. A single well can use millions of gallons of water to hydraulically fracture the rock. After the hydraulic fracturing process is completed, the wastewater must be properly managed.

The significantly greater use of water at Marcellus Shale wells creates a series of environmental issues during the drilling and development of a Marcellus Shale well. First, there are a number of considerations associated with withdrawal of water, including the need to monitor and restrict the amount of withdrawal to avoid dewatering streams and causing pollution. Under State water law, a person who withdrawls water in the amounts generally associated with Marcellus Shale well development shall register the withdrawal with the Department. Second, there are a number of considerations associated with the use and storage of the water used for hydraulic fracturing at the well site or at other locations. Third, there are a number of considerations associated with the proper management, treatment and disposal of the wastewater.

The Department expends considerable staff resources to review the additional information associated with a Marcellus Shale well permit. The fees provided by the final-omitted regulation provide the revenue needed to recover the Department's costs to properly evaluate a Marcellus Shale well permit application and to inspect the activities associated with Marcellus Shale well drilling. Therefore, the fees provided by the final-omitted regulation will remain unchanged.

E. *Summary of Changes Made in the Final-form Rulemaking*

§ 78.1 (relating to definitions)

In response to comments by the Independent Regulatory Review Commission (IRRC), the Department added definitions for Marcellus Shale well, "nonvertical well" and "vertical well."

§ 78.19(d) (relating to underpayment of fee)

In response to several comments, the Department removed the 10% penalty for wells that are drilled longer than the length applied for. As amended, applicants only need to submit the difference between the correct fee and the previously submitted fee.

§ 78.19(e) (relating to money-back guarantee)

This subsection stated that fees were nonrefundable. It was not the Department's intention to withhold fee refunds when the Department fails to take action on well permits within the time period required by the Department's money-back guarantee policy. This subsection has been deleted.

F. *Summary of Comments and Responses on the Proposed Rulemaking*

Fees for traditional wells

Several commentators questioned the size of the fee increase for non-Marcellus Shale wells. They contend that for conventional shallow oil and gas well permitting, either no fee increase is needed or at most, a fee increase that tracks inflation since 1983 would be more appropriate. Using the Consumer Price Index published by the United States Department of Labor's Bureau of Labor Statistics, the fee for the wells would increase from the current $100 as enacted in the act to $216.

The initial $100 permit fee did not cover the program costs in 1984. Program staff and most equipment have primarily been funded by the General Fund. Very few positions, equipment, or emergency well plugging has been funded by permit fees. Indeed, revenue provided by permit fees only covered 15% of the Department's administrative costs in 2008 with the remaining 85% funded through the General Fund. Also, permitting has increased by 398% in just the last 10 years with only recent increases in permitting staff and minimal increases in inspection staff. It is also important to note that the well permit fee is not an annual fee. Therefore, the entire program must be funded through new well permits. To provide the funding needed to employ sufficient staff and provide equipment necessary to carry out the Department's statutory duties through the well permit application fee, as envisioned by section 201(d) of the act, the permit fees must be increased in the amounts provided in the regulation to "bear a reasonable relationship to the cost of administering this act."

Fees based on well bore length

Several commentators questioned the relationship between well bore length and the administrative costs incurred by the Department in reviewing and processing the application.

Section 201(d) of the act states that well permit fees must "bear a reasonable relationship to the cost of administering this act." The Department believes the fee structure satisfies this requirement. While there is not a direct relationship between well bore length and review time, deeper wells do tend to have a greater potential for environmental impacts and this in turn requires greater Department evaluation of the potential impacts. Any set permit fee will necessarily require one group of well drillers to pay more than others if the Department's total costs to administer the program are to be covered by the permit fee as envisioned by the law. The Department believes the ability to bear the cost of increased fees is better able to be borne by operators drilling deeper wells and to do otherwise would place an undue burden on smaller operators.

Penalty for underpayment of fee

Commentators requested deletion of the provision in § 78.19(d) that penalizes the operator if the drilled well bore length exceeds the length specified in the permit application.

This provision has been removed.

Fee refund

Commentators questioned whether the Department would continue to refund permit fees according to its money-back guarantee policy in light of proposed § 78.19(e) which states that fees are nonrefundable.

This subsection has been deleted. It was not the Department's intention to withhold fee refunds where the Department fails to take action on well permits within the time period required by the Department's money-back guarantee policy. However, the Department will not refund permit fees for wells that are permitted but not drilled or for wells that are drilled that have a shorter well bore length than the length permitted.

G. *Benefits, Costs and Compliance*

Benefits

The residents of this Commonwealth and the regulated community will benefit from these regulations because the Department will be able to continue to uphold the purposes of the act. The purposes of the act are to:

(1) Permit the optimal development of the oil and gas resources of this Commonwealth consistent with the protection of the health, safety, environment and property of the citizens of this Commonwealth.

(2) Protect the safety of personnel and facilities employed in the exploration, development, storage and production of natural gas or oil or the mining of coal.

(3) Protect the safety and property rights of persons residing in areas where such exploration, development, storage or production occurs.

(4) Protect the natural resources, environmental rights and values secured by the Pennsylvania Constitution. (58 P. S. § 601.102)

The public will benefit in two general ways. First, the public will benefit from a fiscal perspective when the costs of the regulatory program are imposed on the regulated community, as the act provides. For Marcellus Shale gas well development, the need for timely and special reviews has significantly increased the Department's cost of implementation of the program and it is in the public interest to impose these costs on the regulated community. The public also benefits from an environmental perspective because the Department will be able to hire additional staff to properly inspect new and existing traditional wells and to properly review Marcellus Shale well permit applications.

The regulated community will also benefit because the regulated community wants timely reviews of permit applications, which state law also requires. Having the staff to evaluate well permit applications in a timely and environmentally protective manner will benefit the regulated community and the public.

Costs

This rulemaking will not impose any additional costs on the Department. This proposal will help the Department offset the greater implementation costs to support new and extensive reviews of oil and gas permit applications.

The base fee for vertical wells is $250 with an additional $50 per 500 feet of well bore drilled from 2,000 feet to 5,000 feet and an additional $100 per 500 feet for the well bore drilled past 5,001 feet. Nonvertical wells and Marcellus Shale wells have a base fee of $900 with an additional $100 per 500 feet of well bore drilled past 1,500 feet. An applicant for a vertical well with a well bore length of 1,500 feet or less for home use shall pay a permit application fee of $200.

Compliance Assistance Plan

A compliance assistance plan is not necessary because the new fee structure does not create a situation where a well operator will be out of compliance with the regulation. Well permits that do not contain the appropriate fee are not complete. The Department will return the application to the applicant and tell the applicant what the appropriate fee is. To minimize this circumstance from occurring, the Department will publicize the new permit fee requirements on its web site and inform potential applicants of the new fee structure at upcoming industry trainings.

Paperwork Requirements

No additional paperwork will be required as a result of this rulemaking. However, the Department will need to amend its well permit application form and instructions to incorporate and explain the new permit fee structure.

H. *Sunset Review*

These regulations will be reviewed in accordance with the sunset review schedule published by the Department to determine whether the regulations effectively fulfill the goals for which they were intended.

I. *Regulatory Review*

Under section 5(a) of the Regulatory Review Act (71 P. S. § 745.5(a)), on February 4, 2009, the Department submitted a copy of the notice of proposed rulemaking, published at 39 Pa.B. 838 (February 14, 2009) to IRRC and the House and Senate Environmental Resources and Energy Committees (Committees) for review and comment.

Under section 5(c) of the Regulatory Review Act, IRRC and the Committees were provided with copies of the comments received during the public comment period, as well as other documents when requested. In preparing these final-form regulations, the Department has considered all comments from IRRC, the Committees and the public.

Under section 5.1(j.2) of the Regulatory Review Act (71 P. S. § 745.5a(j.2)), on September 16, 2009, these final-form regulations were deemed approved by the Committees. Under section 5.1(e) of the Regulatory Review Act, IRRC met on September 17, 2009, and approved the final-form regulations.

J. *Findings of the Board*

The Board finds that:

(1) Public notice of proposed rulemaking was given under sections 201 and 202 of the act of July 31, 1968 (P. L. 769, No. 240) (45 P. S. §§ 1201 and 1202) and regulations promulgated thereunder at 1 Pa. Code §§ 7.1 and 7.2 (relating to notice of proposed rulemaking required; and adoption of regulations).

(2) A public comment period was provided as required by law, and all comments were considered.

(3) These regulations do not enlarge the purpose of the proposal published at 39 Pa.B. 838.

(4) These regulations are necessary and appropriate for administration and enforcement of the authorizing acts identified in Section C of this order.

K. *Order of the Board*

The Board, acting under the authorizing statutes, orders that:

(a) The regulations of the Department, 25 Pa. Code Chapter 78, are amended by amending §§ 78.1 and 78.19 to read as set forth in Annex A, with ellipses referring to the existing text of the regulations.

(b) The Chairperson of the Board shall submit this order and Annex A to the Office of General Counsel and the Office of Attorney General for review and approval as to legality and form, as required by law.

(c) The Chairperson of the Board shall submit this order and Annex A to IRRC and the Committees as required by the Regulatory Review Act.

(d) The Chairperson of the Board shall certify this order and Annex A and deposit them with the Legislative Reference Bureau, as required by law.

(e) This order shall take effect immediately.

JOHN HANGER,
Chairperson

(*Editor's Note*: Section 78.15(b) was proposed to be amended at 39 Pa.B. 838. The amendment was adopted pursuant to the rulemaking which appeared at 39 Pa.B. 1982 (April 18, 2009). The proposal to amend § 78.1, amended in this rulemaking, was not included in the proposal at 39 Pa.B. 838.)

(*Editor's Note*: For the text of the order of the Independent Regulatory Review Commission relating to this document, see 39 Pa.B. 5812 (October 3, 2009).)

Fiscal Note: Fiscal Note 7-431 remains valid for the final adoption of the subject regulations.

Annex A

TITLE 25. ENVIRONMENTAL PROTECTION

PART I. DEPARTMENT OF ENVIRONMENTAL PROTECTION

Subpart C. PROTECTION OF NATURAL RESOURCES

ARTICLE I. LAND RESOURCES

CHAPTER 78. OIL AND GAS WELLS

Subchapter A. GENERAL PROVISIONS

§ 78.1. Definitions.

(a) The words and terms defined in section 103 of the act (58 P. S. § 601.103), section 2 of the Coal and Gas Resource Coordination Act (58 P. S. § 502), section 2 of the Oil and Gas Conservation Law (58 P. S. § 402), section 103 of the Solid Waste Management Act (35 P. S. § 6018.103) and section 1 of The Clean Stream Law (35 P. S. § 691.1), have the meanings set forth in those statutes when the terms are used in this chapter.

(b) The following words and terms, when used in this chapter, have the following meanings, unless the context clearly indicates otherwise:

* * * * *

Marcellus Shale well—A well that when drilled or altered produces gas or is anticipated to produce gas from the Marcellus Shale geologic formation.

* * * * *

Nonvertical well—

(i) A well drilled intentionally to deviate from a vertical axis.

(ii) The term includes wells drilled diagonally and wells that have horizonal bore holes.

* * * * *

Vertical well—A well with a single vertical well bore.

* * * * *

Subchapter B. PERMITS, TRANSFERS, AND OBJECTIONS

§ 78.19. Permit application fee schedule.

(a) An applicant shall pay a permit application fee according to the following schedule:

Vertical Wells		**Nonvertical Wells**		**Marcellus Shale Wells**	
Total Well Bore Length in Feet	Total Fee	Total Well Bore Length in Feet	Total Fee	Total Well Bore Length in Feet	Total Fee
0 to 2,000	$250	0 to 1,500	$900	0 to 1,500	$900
2,001 to 2,500	$300	1,501 to 2,000	$1,000	1,501 to 2,000	$1,000
2,501 to 3,000	$350	2,001 to 2,500	$1,100	2,001 to 2,500	$1,100
3,001 to 3,500	$400	2,501 to 3,000	$1,200	2,501 to 3,000	$1,200
3,501 to 4,000	$450	3,001 to 3,500	$1,300	3,001 to 3,500	$1,300
4,001 to 4,500	$500	3,501 to 4,000	$1,400	3,501 to 4,000	$1,400
4,501 to 5,000	$550	4,001 to 4,500	$1,500	4,001 to 4,500	$1,500
5,001 to 5,500	$650	4,501 to 5,000	$1,600	4,501 to 5,000	$1,600
5,501 to 6,000	$750	5,001 to 5,500	$1,700	5,001 to 5,500	$1,700
6,001 to 6,500	$850	5,501 to 6,000	$1,800	5,501 to 6,000	$1,800
6,501 to 7,000	$950	6,001 to 6,500	$1,900	6,001 to 6,500	$1,900
7,001 to 7,500	$1,050	6,501 to 7,000	$2,000	6,501 to 7,000	$2,000
7,501 to 8,000	$1,150	7,001 to 7,500	$2,100	7,001 to 7,500	$2,100
8,001 to 8,500	$1,250	7,501 to 8,000	$2,200	7,501 to 8,000	$2,200
8,501 to 9,000	$1,350	8,001 to 8,500	$2,300	8,001 to 8,500	$2,300
9,001 to 9,500	$1,450	8,501 to 9,000	$2,400	8,501 to 9,000	$2,400
9,501 to 10,000	$1,550	9,001 to 9,500	$2,500	9,001 to 9,500	$2,500
10,001 to 10,500	$1,650	9,501 to 10,000	$2,600	9,501 to 10,000	$2,600
10,501 to 11,000	$1,750	10,001 to 10,500	$2,700	10,001 to 10,500	$2,700
11,001 to 11,500	$1,850	10,501 to 11,000	$2,800	10,501 to 11,000	$2,800
11,501 to 12,000	$1,950	11,001 to 11,500	$2,900	11,001 to 11,500	$2,900
		11,501 to 12,000	$3,000	11,501 to 12,000	$3,000

(b) An applicant for a vertical well exceeding 12,000 feet in total well bore length shall pay a permit application fee of $1,950 + $100 for every 500 feet the well bore extends over 12,000 feet. Fees shall be rounded to the nearest 500-foot interval.

(c) An applicant for a nonvertical well or Marcellus Shale well exceeding 12,000 feet in total well bore length shall pay a permit application fee of $3,000 + $100 for every 500 feet the well bore extends over 12,000 feet. Fees shall be rounded to the nearest 500-foot interval.

(d) If, when drilled, the total well bore length of the well exceeds the length specified in the permit application, the operator shall pay the difference between the amount paid as part of the permit application and the amount required by subsections (a)—(c).

(e) An applicant for a vertical well with a well bore length of 1,500 feet or less for home use shall pay a permit application fee of $200.

(f) At least every 3 years, the Department will provide the EQB with an evaluation of the fees in this chapter and recommend regulatory changes to the EQB to address any disparity between the program income generated by the fees and the Department's cost of administering the program with the objective of ensuring fees meet all program costs and programs are self-sustaining.

[Pa.B. Doc. No. 09-1987. Filed for public inspection October 23, 2009, 9:00 a.m.]

Appendix E: Code for MATLAB Graphing Function, "plotting_many"

```
function [ ] = plotting_many( to_plot1, to_plot2, to_plot3 )
%PLOTTING MANY this function consumes three x by 2 arrays of latitude and
longitude coordinates.  These points are plotted on a map of Pennsylvania in
2D.

xy1=lat_long_helper(to_plot1);
xy2=lat_long_helper(to_plot2);
xy3=lat_long_helper(to_plot3);

%This outlines the state of Pennsylvania:
corners_coord= [
  -0.0038    0.0154;
   -0.0044    0.0145;
   -0.0049    0.0138;
   -0.0054    0.0130;
   -0.0058    0.0122;
   -0.0062    0.0115;
   -0.0069    0.0110;
   -0.0074    0.0104;
   -0.0080    0.0099;
   -0.0086    0.0093;
   -0.0092    0.0087;
   -0.0098    0.0081;
   -0.0104    0.0076;
   -0.0100    0.0070;
   -0.0098    0.0065;
   -0.0093    0.0058;
   -0.0090    0.0052;
   -0.0085    0.0045;
   -0.0081    0.0038;
   -0.0076    0.0032;
   -0.0072    0.0025;
   -0.0068    0.0018;
   -0.0062    0.0008;
   -0.0057   -0.0001;
   -0.0054   -0.0006;
   -0.0048   -0.0015;
   -0.0044   -0.0021;
   -0.0038   -0.0031;
   -0.0031   -0.0041;
   -0.0026   -0.0050;
   -0.0023   -0.0056;
   -0.0018   -0.0063;
   -0.0013   -0.0070;
   -0.0007   -0.0081;
    0.0007   -0.0103;
    0.0016   -0.0118;
    0.0024   -0.0132;
    0.0034   -0.0146;
    0.0044   -0.0163;
    0.0052   -0.0177;
    0.0060   -0.0188;
    0.0067   -0.0199;
    0.0074   -0.0210;
    0.0086   -0.0230;
    0.0094   -0.0243;
    0.0102   -0.0255;
```

```
0.0109   -0.0269;
0.0118   -0.0282;
0.0124   -0.0293;
0.0129   -0.0302;
0.0135   -0.0310;
0.0143   -0.0306;
0.0153   -0.0300;
0.0165   -0.0292;
0.0176   -0.0286;
0.0189   -0.0277;
0.0201   -0.0270;
0.0216   -0.0260;
0.0229   -0.0252;
0.0240   -0.0245;
0.0251   -0.0237;
0.0266   -0.0229;
0.0280   -0.0219;
0.0294   -0.0210;
0.0308   -0.0201;
0.0319   -0.0193;
0.0331   -0.0185;
0.0342   -0.0179;
0.0354   -0.0171;
0.0365   -0.0163;
0.0378   -0.0155;
0.0390   -0.0147;
0.0404   -0.0138;
0.0416   -0.0129;
0.0426   -0.0124;
0.0437   -0.0116;
0.0450   -0.0108;
0.0464   -0.0099;
0.0480   -0.0088;
0.0498   -0.0077;
0.0518   -0.0064;
0.0541   -0.0050;
0.0562   -0.0035;
0.0589   -0.0021;
0.0611    0.0017;
0.0631    0.0023;
0.0647    0.0033;
0.0667    0.0044;
0.0666    0.0051;
0.0667    0.0060;
0.0670    0.0068;
0.0678    0.0075;
0.0687    0.0081;
0.0690    0.0082;
0.0695    0.0082;
0.0698    0.0082;
0.0700    0.0086;
0.0700    0.0089;
0.0701    0.0092;
0.0703    0.0096;
0.0706    0.0098;
0.0709    0.0100;
0.0711    0.0102;
0.0713    0.0105;
0.0714    0.0108;
0.0715    0.0111;
0.0718    0.0113;
0.0720    0.0115;
0.0720    0.0117;
```

```
0.0717    0.0120;
0.0714    0.0124;
0.0714    0.0128;
0.0716    0.0131;
0.0718    0.0134;
0.0718    0.0139;
0.0720    0.0143;
0.0721    0.0148;
0.0722    0.0153;
0.0724    0.0157;
0.0727    0.0159;
0.0729    0.0162;
0.0730    0.0171;
0.0731    0.0174;
0.0733    0.0174;
0.0734    0.0175;
0.0735    0.0177;
0.0736    0.0179;
0.0738    0.0180;
0.0738    0.0184;
0.0736    0.0186;
0.0733    0.0187;
0.0730    0.0188;
0.0727    0.0190;
0.0722    0.0190;
0.0718    0.0189;
0.0714    0.0190;
0.0711    0.0192;
0.0708    0.0193;
0.0704    0.0194;
0.0700    0.0193;
0.0696    0.0194;
0.0692    0.0197;
0.0687    0.0200;
0.0679    0.0196;
0.0673    0.0198;
0.0669    0.0202;
0.0664    0.0209;
0.0660    0.0213;
0.0652    0.0213;
0.0649    0.0208;
0.0643    0.0210;
0.0639    0.0216;
0.0636    0.0220;
0.0632    0.0223;
0.0630    0.0229;
0.0626    0.0233;
0.0627    0.0238;
0.0631    0.0241;
0.0632    0.0245;
0.0630    0.0252;
0.0625    0.0262;
0.0613    0.0268;
0.0609    0.0271;
0.0611    0.0276;
0.0615    0.0287;
0.0614    0.0298;
0.0616    0.0307;
0.0615    0.0324;
0.0612    0.0339;
0.0619    0.0356;
0.0612    0.0360;
0.0606    0.0362;
```

```
    0.0597    0.0359;
    0.0586    0.0355;
    0.0574    0.0354;
    0.0557    0.0362;
    0.0549    0.0373;
    0.0539    0.0386;
    0.0526    0.0392;
    0.0516    0.0390;
    0.0506    0.0387;
    0.0499    0.0394;
    0.0492    0.0394;
    0.0488    0.0395;
    0.0486    0.0397;
    0.0484    0.0397;
    0.0481    0.0395;
    0.0476    0.0392;
    0.0470    0.0388;
    0.0463    0.0383;
    0.0454    0.0376;
    0.0446    0.0371;
    0.0438    0.0365;
    0.0429    0.0359;
    0.0420    0.0353;
    0.0409    0.0345;
    0.0397    0.0337;
    0.0386    0.0329;
    0.0373    0.0320;
    0.0357    0.0309;
    0.0333    0.0293;
    0.0308    0.0276;
    0.0283    0.0259;
    0.0261    0.0244;
    0.0240    0.0230;
    0.0209    0.0209;
    0.0172    0.0185;
    0.0134    0.0160;
    0.0055    0.0109;
    0.0010    0.0079;
   -0.0016    0.0118;
   -0.0039    0.0155  ];

%shift into the first quadrant: Important that all values be positive
%because of later use of Tangent function
corners_coord=[(corners_coord(:,1)+.02),(corners_coord(:,2)+.04)];
x_corn_coord=corners_coord(:,1);
y_corn_coord=corners_coord(:,2);

%rotate to make graph appear familiar
l_rot=sqrt(x_corn_coord.^2+y_corn_coord.^2);
theta_rot=atand(y_corn_coord./x_corn_coord); %this is the polar coord angle
current axis
alpha_rot=33;%this is the angle that we will rotate the current axis
phi_rot=theta_rot-alpha_rot; % this is the angle between the point and rotated
                                %x axis
x_rot=cosd(phi_rot).*l_rot;
y_rot=sind(phi_rot).*l_rot;

hold on
%scatter(corners_coord(:,1), corners_coord(:,2), 'b', 'filled')
%plot(corners_coord(:,1), corners_coord(:,2))

%plots the state border
```

```
plot(x_rot, y_rot);

%Change parameters below to change appearance of graph
scatter(xy1(:,1),xy1(:,2), 22, 'filled', 'g' )
scatter(xy2(:,1),xy2(:,2), 22, 'filled', 'o')
scatter(xy3(:,1),xy3(:,2), 22, 'filled', 'k')

scatter(xy3(:,1),xy3(:,2), 25,  'k' )
%scatter(xy2(:,1),xy2(:,2), 25,  'k')

%Change title below
title('2010 and 2011 CEMENTING/CASING VIOLATIONS PA,g=permits 2010/2011,
red=2010 violations, black outline= 2011 violations')
end
```

Appendix F: Code for Helper Function, "lat_long_helper"

```
function [ output ] = lat_long_helper( coord_lat_long )
%LAT_LONG
%   This function consumes latitude and longitude coordinates in an x by 2 array and
converts them to x, y coordinates.

%  enter coordinates like this
%  coord_lat_long=[phi1 theta1; phi2 theta2]
%  where phi is latidude
%        theta is longitude

R=1; %Radius of earth, doesnt matter what this is..., its all about angle

%%
%Three points in PA, used for triangulating
%Venango Museum, point 1
vm_lat_long=[ 41.435761176807084 -79.70901846885681];
%Meadville Medical, point 2
mm_lat_long= [41.641802235601474 -80.14575719833374];
%Brokenstraw Airport, point 3
ba_lat_long=[ 41.832351348868045 -79.35991287231445];


three_points_lat_long=[vm_lat_long; mm_lat_long; ba_lat_long];

phi_three_points=three_points_lat_long(:,1);
theta_three_points= three_points_lat_long(:,2);

Z_tri= sind(phi_three_points)*R;
Y_tri=cosd(theta_three_points).*cosd(phi_three_points)*R;
X_tri=-sind(theta_three_points).*cosd(phi_three_points)*R;



%%

phi=coord_lat_long(:,1);
theta= coord_lat_long(:,2);

%convert to rectangular coordinates, EARTH FRAME:
Z= sind(phi)*R;
Y=cosd(theta).*cosd(phi)*R;
X=-sind(theta).*cosd(phi)*R;

% figure
% scatter3(X,Y,Z)
% xlabel('x')
% ylabel('y')
% zlabel('z')

%Distances between the three test points and the points to be plotted
d1=sqrt((X_tri(1)-X).^2 + (Y_tri(1)-Y).^2 + (Z_tri(1)-Z).^2);
d2=sqrt((X_tri(2)-X).^2 + (Y_tri(2)-Y).^2 + (Z_tri(2)-Z).^2);
d3=sqrt((X_tri(3)-X).^2 + (Y_tri(3)-Y).^2 + (Z_tri(3)-Z).^2);
```

```
%Distance between the three test points
l32=sqrt((X_tri(3)-X_tri(2))^2 + (Y_tri(3)-Y_tri(2))^2 + (Z_tri(3)-Z_tri(2))^2);
l21=sqrt((X_tri(1)-X_tri(2))^2 + (Y_tri(1)-Y_tri(2))^2 + (Z_tri(1)-Z_tri(2))^2);
l31=sqrt((X_tri(1)-X_tri(3))^2 + (Y_tri(1)-Y_tri(3))^2 + (Z_tri(1)-Z_tri(3))^2);

%angle between l32 and l21
alpha=acosd((l31^2-l21^2-l32^2)/(-2*l21*l32));

%coordintates of three known points using point 2 as the origin.  In my
%coordinate system, point 1 lies on the x axis.
xyp1=[l21 0];
xyp2=[0 0];
xyp2=[l32*cosd(alpha),l32*sind(alpha)];

%Now find the x and y coordinates of the points to be plotted
%the x coordinate
beta=acosd((d1.^2-d2.^2-l21^2)./(-2*d2.*l21));
x_coord=cosd(beta).*d2;

%two possible y coordinates, a and b
y_coord_a=[sind(beta).*d2];
y_coord_b=[-sind(beta).*d2];
y_coord_ab=[y_coord_a, y_coord_b];

%Because we are triangulating the position, there are two possible y
%coordinates and the third point, point 3, can be used to find which is the
%correct coordinate of the two options.
%the t values are the distances between the point to be plotted and point
%3.  The t value that equals d3 corresponds to the correct y coordinate.
t_a=[sqrt((xyp2(1)-x_coord).^2+(xyp2(2)-y_coord_a).^2)];
t_b=[sqrt((xyp2(1)-x_coord).^2+(xyp2(2)-y_coord_b).^2)];
d3;

%compare_y=[t_a, t_b, d3];
compare_y=[abs(t_a-d3), abs(t_b-d3)];
A=compare_y(:,1);
B=compare_y(:,2);
n=length(A);
C=ones(n,1);

%when A is greater than B than B corresponds to the correct y coord and the
%returned value in B should be 2.
for k=1:1:n
if (A(k)>B(k));
    C(k)=2;
else
    C(k)=1;
end
end

y_coord=ones(n,1);
for p=1:1:n
    index=C(p);
    y_coord(p)=y_coord_ab(p, index);

end
y_coord;

%shift to first quadrant
```

```
x_coord=x_coord+ .02;
y_coord=y_coord + .04;

%rotate
l_rot=sqrt(x_coord.^2+y_coord.^2);
theta_rot=atand(y_coord./x_coord); %this is the polar coord angle current axis
alpha_rot=33;%this is the angle that we will rotate the current axis
phi_rot=theta_rot-alpha_rot; % this is the angle between the point and rotated
                                %x axis
x_rot=cosd(phi_rot).*l_rot;
y_rot=sind(phi_rot).*l_rot;

output=[x_rot, y_rot];
%output=[x_coord, y_coord];

end
```

Appendix G: Cementing and Well Casing Data Sheet, 2011

	B	C	D	E	M	N	O
1	Operator1	LAT	LONG	Permit#	Date Violation	Violation Code	Violation Desc
2	CABOT OIL & GAS CORP	41.75109444	-75.86802778	115-20223	05-Jan-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
3	CABOT OIL & GAS CORP	41.75108889	-75.86791667	115-20224	05-Jan-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
4	CABOT OIL & GAS CORP	41.75108056	-75.86780833	115-20284	05-Jan-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
5	CABOT OIL & GAS CORP	41.75109444	-75.86802778	115-20223	05-Jan-2011	207B	Failure to case and cement to prevent migrations into fresh groundwater
6	CABOT OIL & GAS CORP	41.75108889	-75.86791667	115-20224	05-Jan-2011	207B	Failure to case and cement to prevent migrations into fresh groundwater
7	CABOT OIL & GAS CORP	41.75108056	-75.86780833	115-20284	05-Jan-2011	207B	Failure to case and cement to prevent migrations into fresh groundwater
8	CHIEF OIL & GAS LLC	41.27089244	-76.65969119	081-20109	10-Jan-2011	78.85	Inadequate, insufficient, and/or improperly installed cement
9	CHIEF OIL & GAS LLC	41.27080356	-76.65974675	081-20119	10-Jan-2011	78.85	Inadequate, insufficient, and/or improperly installed cement
10	CHIEF OIL & GAS LLC	41.28121389	-76.631075	081-20149	10-Jan-2011	78.85	Inadequate, insufficient, and/or improperly installed cement
11	CHIEF OIL & GAS LLC	41.27227222	-76.63653056	081-20205	10-Jan-2011	78.85	Inadequate, insufficient, and/or improperly installed cement
12	CHIEF OIL & GAS LLC	41.27218611	-76.63658889	081-20209	10-Jan-2011	78.85	Inadequate, insufficient, and/or improperly installed cement
13	CHIEF OIL & GAS LLC	41.27221111	-76.636525	081-20210	10-Jan-2011	78.85	Inadequate, insufficient, and/or improperly installed cement
14	CHIEF OIL & GAS LLC	41.27089244	-76.65969119	081-20109	10-Jan-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
15	CHIEF OIL & GAS LLC	41.27080356	-76.65974675	081-20119	10-Jan-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days

	B	C	D	E	M	N	O
16	CHIEF OIL & GAS LLC	41.28121389	-76.631075	081-20149	10-Jan-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
17	CHIEF OIL & GAS LLC	41.27227222	-76.63653056	081-20205	10-Jan-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
18	CHIEF OIL & GAS LLC	41.27218611	-76.63658889	081-20209	10-Jan-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
19	CHIEF OIL & GAS LLC	41.27221111	-76.636525	081-20210	10-Jan-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
20	PA GEN ENERGY CO LLC	41.84959722	-78.14620556	105-21672	27-Jan-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
21	PA GEN ENERGY CO LLC	41.84679167	-78.15653056	105-21682	27-Jan-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
22	PA GEN ENERGY CO LLC	41.84680556	-78.15642222	105-21684	27-Jan-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
23	RESOURCES APPALACHIA LLC	41.33167147	-77.28228356	081-20238	14-Feb-2011	78.85	Inadequate, insufficient, and/or improperly installed cement
24	PRODUCTION APPALACHIA LLC	41.924375	-75.8729	115-20461	15-Feb-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
25	RESOURCES APPALACHIA LLC	41.32306389	-77.2915	081-20385	16-Feb-2011	78.85	Inadequate, insufficient, and/or improperly installed cement
26	RESOURCES APPALACHIA LLC	41.33175	-77.28230556	081-20238	22-Feb-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
27	RESOURCES APPALACHIA LLC	41.32306389	-77.2915	081-20385	22-Feb-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
28	EOG RESOURCES INC	41.16259286	-78.45328958	033-26829	02-Mar-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
29	CHESAPEAKE APPALACHIA LLC	41.76341944	-76.51021389	015-20221	03-Mar-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
30	CHESAPEAKE APPALACHIA LLC	41.87778333	-76.309375	015-20871	03-Mar-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days

	B	C	D	E	M	N	O
31	CHESAPEAKE APPALACHIA LLC	41.70880278	-76.01491111	115-20426	03-Mar-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
32	CHESAPEAKE APPALACHIA LLC	41.60834444	-76.37353889	015-20702	04-Mar-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
33	ANADARKO E&P CO LP	41.369225	-77.55945833	035-21234	08-Mar-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
34	CHESAPEAKE APPALACHIA LLC	41.75123611	-76.73583611	015-20759	22-Mar-2011	78.83GRN DWTR	Improper casing to protect fresh groundwater
35	CHESAPEAKE APPALACHIA LLC	41.75124444	-76.73578333	015-20760	22-Mar-2011	78.83GRN DWTR	Improper casing to protect fresh groundwater
36	SENECA RESOURCES CORP	41.739055	-77.10461806	117-20822	22-Mar-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
37	CABOT OIL & GAS CORP	41.69765278	-75.85495833	115-20406	30-Mar-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
38	SWEPI LP	41.79733889	-77.24435556	117-20674	06-Apr-2011	78.73A	Operator shall prevent gas and other fluids from lower formations from entering fresh groundwater.
39	NOVUS OPERATING LLC	41.97487222	-77.56043889	117-20532	07-Apr-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
40	PENN VIRGINIA OIL & GAS CORP	41.95839464	-77.60756064	117-20480	07-Apr-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
41	CHIEF OIL & GAS LLC	41.73026389	-76.330425	015-21341	14-Apr-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
42	CHIEF OIL & GAS LLC	41.73015	-76.33058611	015-21352	14-Apr-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
43	CHESAPEAKE APPALACHIA LLC	41.81438889	-76.33284722	015-21180	20-Apr-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
44	SOUTHWESTERN ENERGY PROD CO	41.77288056	-76.20693611	015-20837	11-May-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
45	XTO ENERGY INC	41.21089722	-76.622575	081-20295	17-May-2011	78.73A	Operator shall prevent gas and other fluids from lower formations from entering fresh groundwater.

	B	C	D	E	M	N	O
46	CHESAPEAKE APPALACHIA LLC	41.71473056	-76.29068333	015-20720	18-May-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
47	CHESAPEAKE APPALACHIA LLC	41.87779444	-76.30932222	015-20865	18-May-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
48	FLATIRONS DEVELOPMENT LLC	41.22831944	-78.72297222	065-26927	18-May-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
49	XTO ENERGY INC	41.25960278	-76.57779722	081-20432	02-Jun-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
50	XTO ENERGY INC	41.25961111	-76.57783056	081-20433	07-Jun-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
51	EXCO RESOURCES PA INC	41.04860556	-79.23399722	031-25524	09-Jun-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
52	SENECA RESOURCES CORP	41.21720681	-78.68433306	047-24364	16-Jun-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
53	CHESAPEAKE APPALACHIA LLC	41.71468889	-76.29068056	015-20719	17-Jun-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
54	CHESAPEAKE APPALACHIA LLC	41.71851944	-76.274075	015-20715	21-Jun-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
55	CHESAPEAKE APPALACHIA LLC	41.7185	-76.27402778	015-20857	21-Jun-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
56	CHESAPEAKE APPALACHIA LLC	41.72333333	-76.24623333	015-20922	21-Jun-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
57	CHESAPEAKE APPALACHIA LLC	41.72331111	-76.24618889	015-20923	21-Jun-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
58	XTO ENERGY INC	41.36706667	-77.67051667	035-21217	24-Jun-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
59	CHESAPEAKE APPALACHIA LLC	41.639275	-75.97329722	131-20033	30-Jun-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
60	XTO ENERGY INC	41.21089722	-76.622575	081-20295	07-Jul-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days

	B	C	D	E	M	N	O
61	XTO ENERGY INC	41.22161111	-76.62961389	081-20296	07-Jul-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
62	XTO ENERGY INC	41.19969444	-76.63206944	081-20300	07-Jul-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
63	XTO ENERGY INC	41.21091111	-76.62264444	081-20402	07-Jul-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
64	XTO ENERGY INC	41.21090556	-76.62260833	081-20403	07-Jul-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
65	XTO ENERGY INC	41.23392778	-76.63373611	081-20287	11-Jul-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
66	XTO ENERGY INC	41.23955278	-76.63860278	081-20496	11-Jul-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
67	XTO ENERGY INC	41.23420556	-76.644075	081-20532	11-Jul-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
68	CHESAPEAKE APPALACHIA LLC	41.63863889	-76.09874444	131-20062	13-Jul-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
69	CHESAPEAKE APPALACHIA LLC	41.87778333	-76.309375	015-20871	13-Jul-2011	78.84	Insufficient casing strength, thickness, and installation equipment
70	PRODUCTION APPALACHIA LLC	41.91721667	-75.83270833	115-20526	20-Jul-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
71	CHESAPEAKE APPALACHIA LLC	41.58280278	-76.53495278	015-21512	29-Jul-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
72	EXCO RESOURCES PA LLC	41.28207583	-77.25216833	081-20277	11-Aug-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
73	SENECA RESOURCES CORP	41.62644722	-78.71174444	083-55281	17-Aug-2011	207B	Failure to case and cement to prevent migrations into fresh groundwater
74	SENECA RESOURCES CORP	41.62648611	-78.71175278	083-55282	17-Aug-2011	207B	Failure to case and cement to prevent migrations into fresh groundwater
75	CHESAPEAKE APPALACHIA LLC	41.78290278	-76.33094167	015-20732	18-Aug-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days

	B	C	D	E	M	N	O
76	HESS CORP	41.99450556	-75.47166667	127-20020	18-Aug-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
77	HESS CORP	41.99450556	-75.47166667	127-20020	18-Aug-2011	78.85	Inadequate, insufficient, and/or improperly installed cement
78	EXCO RESOURCES PA LLC	41.28125833	-76.63128611	081-20361	22-Aug-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
79	EXCO RESOURCES PA LLC	41.28123056	-76.63114444	081-20362	22-Aug-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
80	EXCO RESOURCES PA LLC	41.28124444	-76.63121667	081-20365	22-Aug-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
81	EXCO RESOURCES PA LLC	41.281275	-76.63135556	081-20456	22-Aug-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
82	CHESAPEAKE APPALACHIA LLC	41.84690556	-76.31299444	015-21388	23-Aug-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
83	CHESAPEAKE APPALACHIA LLC	41.81543611	-76.45683611	015-21403	23-Aug-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
84	CHEVRON APPALACHIA LLC	39.93697222	-79.87321111	051-24426	29-Aug-2011	78.83COA LCSG	Improper coal protective casing and cementing procedures
85	EQT PRODUCTION CO	40.72283333	-79.42113889	005-30720	07-Sep-2011	78.83COA LCSG	Improper coal protective casing and cementing procedures
86	PRODUCTION APPALACHIA LLC	41.97679167	-75.77985547	115-20205	13-Sep-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
87	PRODUCTION APPALACHIA LLC	41.97678611	-75.77997778	115-20580	13-Sep-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
88	XTO ENERGY INC	41.24942778	-76.45625	037-20004	19-Sep-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
89	CHESAPEAKE APPALACHIA LLC	41.62782778	-76.07386667	131-20169	20-Sep-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
90	RESOURCES APPALACHIA LLC	41.30522778	-77.29558333	081-20313	23-Sep-2011	78.83GRN DWTR	Improper casing to protect fresh groundwater

	B	C	D	E	M	N	O
91	RESOURCES APPALACHIA LLC	41.30911111	-77.28799444	081-20489	23-Sep-2011	78.83GRN DWTR	Improper casing to protect fresh groundwater
92	ANADARKO E&P CO LP	41.433325	-77.20871944	081-20462	06-Oct-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
93	ANADARKO E&P CO LP	41.43320556	-77.20856944	081-20467	06-Oct-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
94	RESOURCES APPALACHIA LLC	41.362025	-77.03818333	081-20596	18-Oct-2011	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
95	SNYDER BROS INC	40.90459444	-79.4523	005-30823	21-Oct-2011	78.83COA LCSG	Improper coal protective casing and cementing procedures
96	CNX GAS CO LLC	40.09231389	-80.29861667	125-24517	27-Oct-2011	78.83GRN DWTR	Improper casing to protect fresh groundwater

Appendix H: Cementing and Well Casing Data Sheet, 2010

	A	B	C	E	K	L	M	N
1	**Operator1**	**Lat**	**Long**	**Permit #**	**Date Inspected**	**Date Violation**	**Violation Co**	**Violation Desc**
2	ANADARKO E&P CO LP	41.344905	-77.267819	081-20194	05-Nov-2010	05-Nov-2010	78.85	Inadequate, insufficient, and/or improperly installed cement
3	ANADARKO E&P CO LP	41.345094	-77.267836	081-20195	05-Nov-2010	05-Nov-2010	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
4	ANADARKO E&P CO LP	41.308062	-76.668405	081-20196	20-Dec-2010	20-Dec-2010	78.85	Inadequate, insufficient, and/or improperly installed cement
5	ANADARKO E&P CO LP	41.345069	-77.267811	081-20197	20-Dec-2010	20-Dec-2010	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
6	ANADARKO E&P CO LP	41.474156	-77.245307	081-20254	16-Dec-2010	16-Dec-2010	78.85	Inadequate, insufficient, and/or improperly installed cement
7	ANADARKO E&P CO LP	41.26205	-76.618992	081-20255	16-Dec-2010	16-Dec-2010	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
8	ANADARKO E&P CO LP	41.292655	-77.38909	081-20256	20-Dec-2010	20-Dec-2010	78.85	Inadequate, insufficient, and/or improperly installed cement
9	ANADARKO E&P CO LP	41.292675	-77.38914	081-20257	20-Dec-2010	20-Dec-2010	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
10	ATLAS RESOURCES LLC	39.830833	-79.983258	059-25334	13-Apr-2010	13-Apr-2010	78.83COALCSG	Improper coal protective casing and cementing procedures
11	BURNETT OIL CO INC	40.332028	-79.095972	129-28411	27-Oct-2010	27-Oct-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
12	BURNETT OIL CO INC	40.32919167	-79.2566028	129-28412	27-Oct-2010	27-Oct-2010	78.83COALCSG	Improper coal protective casing and cementing procedures
13	CABOT OIL & GAS CORP	41.744775	-75.922322	115-20367	07-Dec-2010	07-Dec-2010	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
14	CABOT OIL & GAS CORP	41.74465	-75.922319	115-20368	07-Dec-2010	07-Dec-2010	207B	Failure to case and cement to prevent migrations into fresh groundwater
15	CHESAPEAKE APPALACHIA LLC	41.779097	-76.650508	015-20665	07-Dec-2010	07-Dec-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater

	Operator1	Lat	Long	Permit #	Date Inspected	Date Violation	Violation Code	Violation Desc
16	CHESAPEAKE APPALACHIA LLC	41.667356	-76.740831	015-20758	01-Jul-2010	01-Jul-2010	78.73B	Excessive casing seat pressure
17	CHESAPEAKE APPALACHIA LLC	41.683206	-76.656069	015-20932	18-Aug-2010	18-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
18	CHESAPEAKE APPALACHIA LLC	41.639314	-75.973297	131-20037	23-Nov-2010	23-Nov-2010	207B	Failure to case and cement to prevent migrations into fresh groundwater
19	CHESAPEAKE APPALACHIA LLC	41.639314	-75.973297	131-20037	03-Dec-2010	03-Dec-2010	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
20	CHIEF OIL & GAS LLC	40.35325278	-78.5658583	013-20013	29-Nov-2010	29-Nov-2010	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
21	CHIEF OIL & GAS LLC	40.36057778	-78.5559028	013-20014	29-Nov-2010	29-Nov-2010	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
22	CHIEF OIL & GAS LLC	40.353253	-78.565786	013-20015	29-Nov-2010	29-Nov-2010	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
23	CHIEF OIL & GAS LLC	41.272219	-76.636656	081-20144	29-Jan-2010	29-Jan-2010	78.85	Inadequate, insufficient, and/or improperly installed cement
24	CHIEF OIL & GAS LLC	41.272219	-76.636656	081-20144	27-Jan-2010	27-Jan-2010	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
25	CHIEF OIL & GAS LLC	41.697739	-75.840136	115-20212	12-Oct-2010	12-Oct-2010	207B	Failure to case and cement to prevent migrations into fresh groundwater
26	CHIEF OIL & GAS LLC	41.697739	-75.840136	115-20212	12-Oct-2010	12-Oct-2010	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
27	CHIEF OIL & GAS LLC	41.697639	-75.840083	115-20377	12-Oct-2010	12-Oct-2010	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
28	EAST RESOURCES INC	41.9883815	-76.9908483	117-20409	18-Mar-2010	18-Mar-2010	78.81D2	Failure to case and cement properly through storage reservoir or storage horizon
29	EAST RESOURCES INC	41.9883815	-76.9908483	117-20409	18-Mar-2010	18-Mar-2010	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
30	EAST RESOURCES MGMT LLC	41.77078	-77.40974	117-20598	29-Jul-2010	29-Jul-2010	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days

	A	B	C	E	K	L	M	N
1	Operator1	Lat	Long	Permit #	Date Inspected	Date Violation	Violation Code	Violation Desc
31	EAST RESOURCES MGMT LLC	41.803289	-77.149142	117-20753	13-Dec-2010	13-Dec-2010	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
32	ENERGY CORP OF AMER	41.113127	-78.406752	033-26848	06-Dec-2010	06-Dec-2010	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
33	ENERGY CORP OF AMER	41.113057	-78.406691	033-26855	06-Dec-2010	06-Dec-2010	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
34	EOG RESOURCES INC	41.16264	-78.453223	033-26872	04-Jun-2010	04-Jun-2010	209BOP	Inadequate or improperly installed BOP, other safety devices, or no certified BOP operator
35	EXCO RESOURCES PA INC	40.74592536	-79.5082389	005-30493	26-Feb-2010	26-Feb-2010	78.85	Inadequate, insufficient, and/or improperly installed cement
36	PENN VIRGINIA OIL & GAS CORP	41.958395	-77.607561	117-20480	30-Mar-2010	30-Mar-2010	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
37	REX ENERGY OPERATING CORPORATION	40.838639	-80.054944	019-21674	14-Sep-2010	14-Sep-2010	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
38	SENECA RESOURCES CORP	41.22133	-78.688845	047-24431	27-Jul-2010	27-Jul-2010	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
39	SNYDER BROS INC	40.80025278	-79.6389556	005-30231	13-Aug-2010	13-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
40	STONE ENERGY CORP	41.766081	-76.103799	115-20258	02-Sep-2010	02-Sep-2010	207B	Failure to case and cement to prevent migrations into fresh groundwater
41	STONE ENERGY CORP	41.766081	-76.103799	115-20258	02-Sep-2010	02-Sep-2010	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
42	STONE ENERGY CORP	41.766042	-76.103753	115-20392	02-Sep-2010	02-Sep-2010	207B	Failure to case and cement to prevent migrations into fresh groundwater
43	STONE ENERGY CORP	41.766042	-76.103753	115-20392	02-Sep-2010	02-Sep-2010	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
44	TALISMAN ENERGY USA INC	41.86194167	-76.8477167	015-20427	04-Aug-2010	04-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
45	TALISMAN ENERGY USA INC	41.861925	-76.8476278	015-20428	04-Aug-2010	04-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater

	A	B	C	E	K	L	M	N
1	Operator1	Lat	Long	Permit #	Date Inspected	Date Violation	Violation Cod	Violation Desc
46	TALISMAN ENERGY USA INC	41.861894	-76.847447	015-20430	04-Aug-2010	04-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
47	TALISMAN ENERGY USA INC	41.861597	-76.847758	015-20461	04-Aug-2010	04-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
48	TALISMAN ENERGY USA INC	41.861581	-76.847669	015-20462	04-Aug-2010	04-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
49	TALISMAN ENERGY USA INC	41.861564	-76.847581	015-20463	04-Aug-2010	04-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
50	TALISMAN ENERGY USA INC	41.86155	-76.847492	015-20464	04-Aug-2010	04-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
51	TALISMAN ENERGY USA INC	41.749503	-76.833408	015-20489	04-Aug-2010	04-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
52	TALISMAN ENERGY USA INC	41.749519	-76.833317	015-20490	04-Aug-2010	04-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
53	TALISMAN ENERGY USA INC	41.749536	-76.833231	015-20491	04-Aug-2010	04-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
54	TALISMAN ENERGY USA INC	41.749642	-76.833408	015-20492	04-Aug-2010	04-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
55	TALISMAN ENERGY USA INC	41.749658	-76.833319	015-20493	04-Aug-2010	04-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
56	TALISMAN ENERGY USA INC	41.749675	-76.833231	015-20494	04-Aug-2010	04-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
57	TALISMAN ENERGY USA INC	41.879461	-76.865364	015-20505	04-Aug-2010	04-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
58	TALISMAN ENERGY USA INC	41.87946	-76.865456	015-20506	04-Aug-2010	04-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
59	TALISMAN ENERGY USA INC	41.879185	-76.865207	015-20508	04-Aug-2010	04-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
60	TALISMAN ENERGY USA INC	41.879184	-76.865299	015-20509	04-Aug-2010	04-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater

	A	B	C	E	K	L	M	N
1	Operator1	Lat	Long	Permit #	Date Inspected	Date Violation	Violation Code	Violation Desc
61	TALISMAN ENERGY USA INC	41.879182	-76.865391	015-20510	04-Aug-2010	04-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
62	TALISMAN ENERGY USA INC	41.879181	-76.865482	015-20511	04-Aug-2010	04-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
63	TALISMAN ENERGY USA INC	41.711094	-76.838247	015-20593	03-Aug-2010	03-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
64	TALISMAN ENERGY USA INC	41.711094	-76.838247	015-20593	23-Nov-2010	23-Nov-2010	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
65	TALISMAN ENERGY USA INC	41.711164	-76.838231	015-20594	23-Nov-2010	23-Nov-2010	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
66	TALISMAN ENERGY USA INC	41.690047	-76.852675	015-20603	16-Aug-2010	16-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
67	TALISMAN ENERGY USA INC	41.750092	-76.838783	015-20613	04-Aug-2010	04-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
68	TALISMAN ENERGY USA INC	41.750111	-76.838656	015-20614	04-Aug-2010	04-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
69	TALISMAN ENERGY USA INC	41.750372	-76.838792	015-20616	04-Aug-2010	04-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
70	TALISMAN ENERGY USA INC	41.750392	-76.838667	015-20617	04-Aug-2010	04-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
71	TALISMAN ENERGY USA INC	41.750411	-76.838542	015-20618	04-Aug-2010	04-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
72	TALISMAN ENERGY USA INC	41.755906	-76.826892	015-20626	04-Aug-2010	04-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
73	TALISMAN ENERGY USA INC	41.75595	-76.826825	015-20627	04-Aug-2010	04-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
74	TALISMAN ENERGY USA INC	41.755997	-76.826756	015-20628	04-Aug-2010	04-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
75	TALISMAN ENERGY USA INC	41.756044	-76.826689	015-20629	04-Aug-2010	04-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater

	A	B	C	E	K	L	M	N
1	**Operator1**	**Lat**	**Long**	**Permit #**	**Date Inspected**	**Date Violation**	**Violation Co**	**Violation Desc**
76	TALISMAN ENERGY USA INC	41.724808	-76.782747	015-20772	03-Aug-2010	03-Aug-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
77	ULTRA RESOURCES INC	41.705033	-77.530692	117-20348	29-Jul-2010	29-Jul-2010	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
78	WILLIAMS PRODUCTION APPALACHIA LLC	41.969817	-75.887829	115-20188	29-Sep-2010	29-Sep-2010	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
79	XTO ENERGY INC	40.534092	-79.198464	063-36827	28-May-2010	28-May-2010	78.83GRNDWTR	Improper casing to protect fresh groundwater
80	XTO ENERGY INC	41.239577	-76.638618	081-20275	21-Dec-2010	21-Dec-2010	78.85	Inadequate, insufficient, and/or improperly installed cement
81	XTO ENERGY INC	41.239577	-76.638618	081-20275	21-Dec-2010	21-Dec-2010	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
82	XTO ENERGY INC	41.239603	-76.638631	081-20348	21-Dec-2010	21-Dec-2010	78.85	Inadequate, insufficient, and/or improperly installed cement
83	XTO ENERGY INC	41.239603	-76.638631	081-20348	21-Dec-2010	21-Dec-2010	78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days

Appendix I: Cementing and Well Casing Data Sheet, 2009

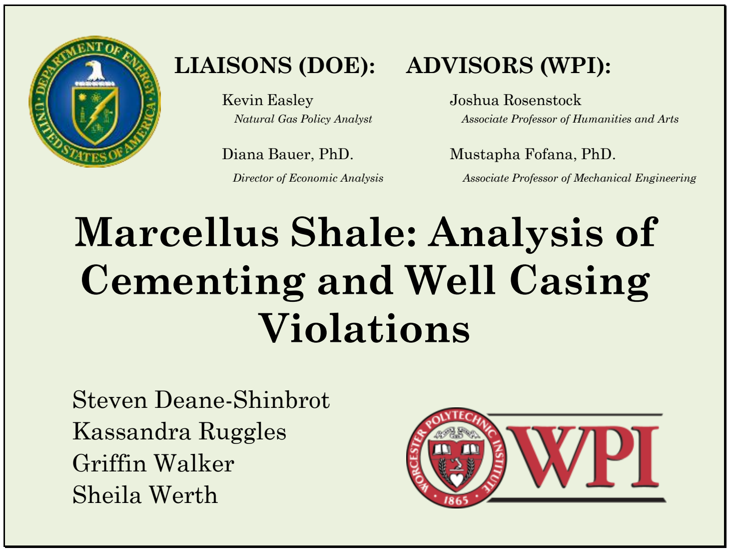
Operator	Permit#	Date Inspected	Date Violatior	Violation Code	Violation Desc
MDS ENERGY LTD	005-30250	30-Dec-2009	30-Dec-2009	207B	Failure to case and cement to prevent
MDS ENERGY LTD	005-30336	03-Jun-2009	03-Jun-2009	78.83GRNDWTR	Improper casing to protect fresh groundwater
CABOT OIL & GAS CORP	115-20019	05-May-2009	05-May-2009	78.86	Failure to report defective, insufficient, or

Appendix J: Cementing and Well Casing Data Sheet, 2008

Operator	Permit#	Date Inspecte	Date Violatio	Violation Cod	Violation Desc
CABOT OIL & GAS CORP	115-20026	20-Aug-2008	20-Aug-2008	78.83GRNDWTR	Improper casing to protect fresh groundwater
EAST RESOURCES INC	117-20202	21-Aug-2008	21-Aug-2008	78.83GRNDWTR	Improper casing to protect fresh groundwater

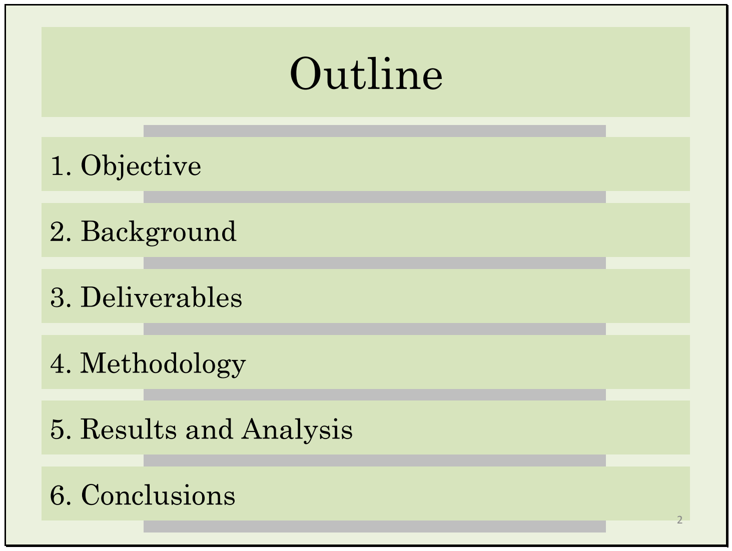
Appendix K: Final Presentation Slides

Slide 1



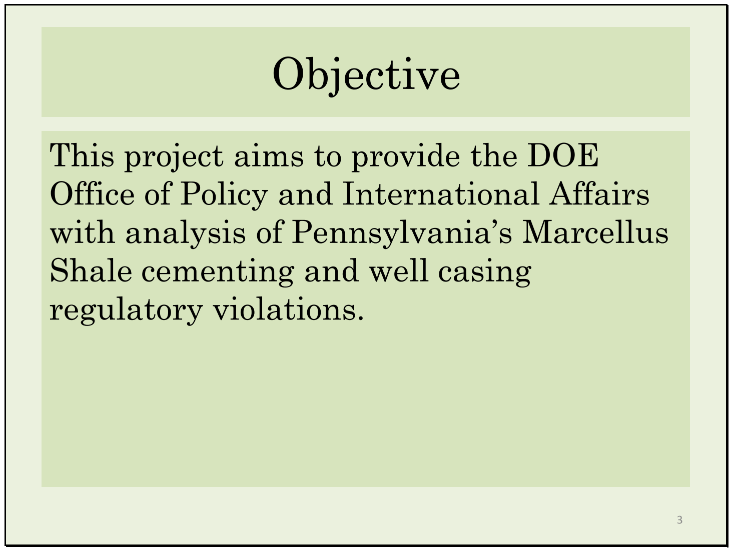
Good afternoon, we are the WPI project team working with the United States Department of Energy. My name is ……..Our project is Marcellus Shale: Analysis of Cementing and Well Casing Violations. At this time we would like to acknowledge our advisors, Professors Joshua Rosenstock and Mustapha Fofana. We would also like to recognize our liasons here at the DOE, Kevin Easley and Diana Bauer.

Slide 2



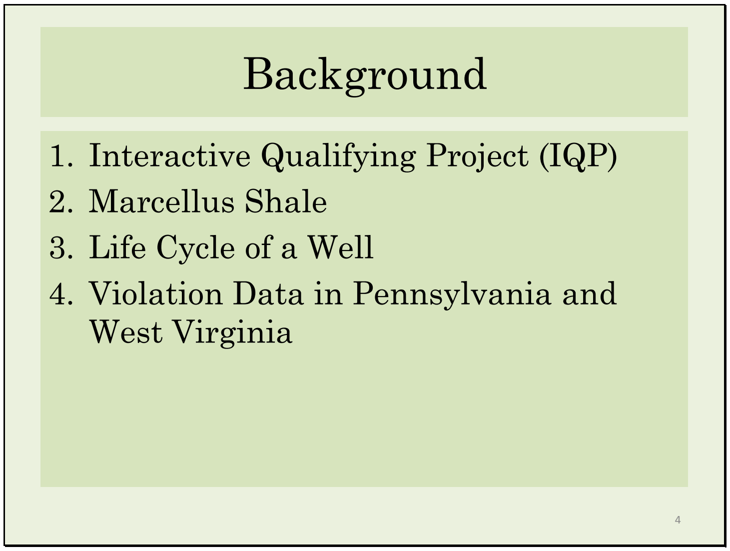
This is the outline of our presentation. We will begin with our goals and our objectives of this project. From there we will move onto the background needed to understand this complex issue. After that we will explain our deliverable items and delve into our methodology for creating those deliverables. In addition, we will explain our results and analysis from our project and finish off this presentation with our conclusions from our research.

Slide 3



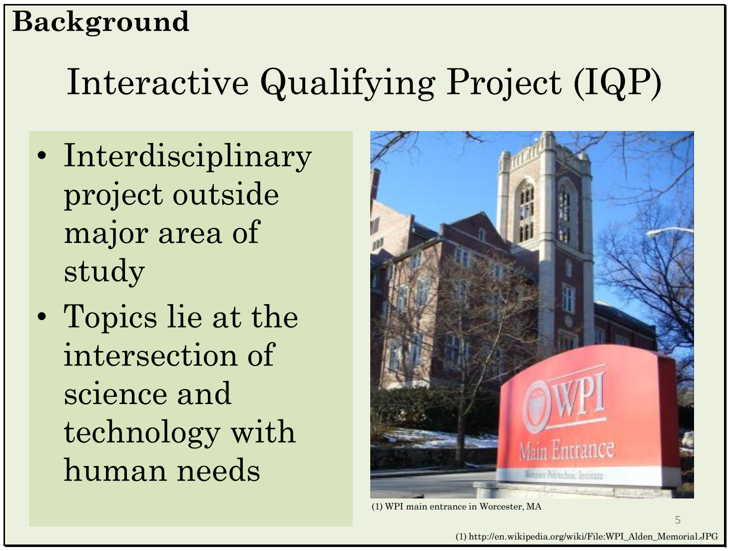
The objective of our project was to assist the DOE Office of Policy and International affairs by identifying and explaining trends in Pennsylvania cementing and well casing violations. In order to do this we first had to understand the background of this topic.

Slide 4



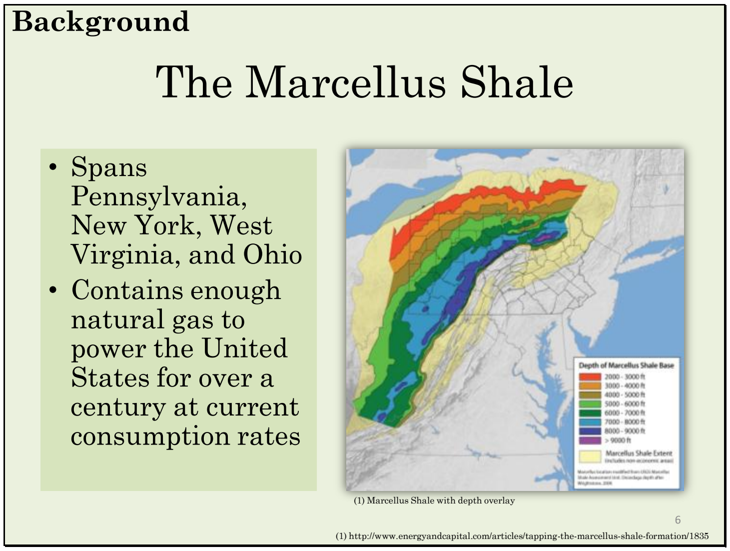
This is an outline of our background for our presentation. First we will explain what an IQP is. Next, we plan to explain the Marcellus Shale and major issues associated with our project. After that, we will explain the life cycle of a well. We will finish this section by explaining the Violation data in Pennsylvania and West Virginia.

Slide 5



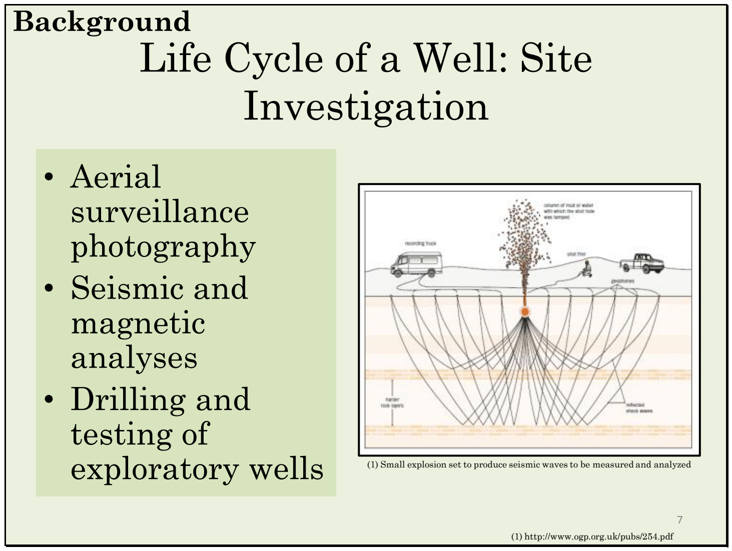
For those of you unfamiliar with us, we come from Worcester Polytechnic Institute located in Worcester, MA. It's primarily an engineering school with a project based curriculum. Concerning these projects, in our junior year we do our Interactive Qualifying Project or IQP. This is meant to be outside our major area of study and is meant to be at the intersection of science and technology with human needs.

Slide 6



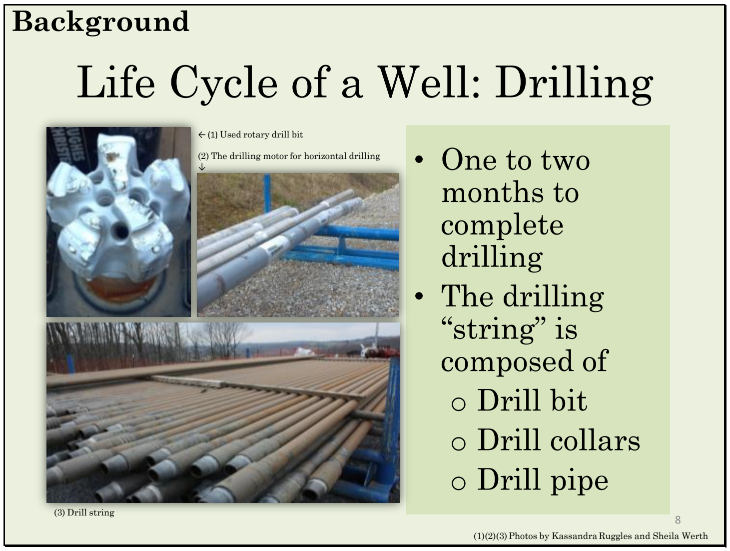
The Marcellus Shale is located in Pennsylvania, New York, West Virginia, and Ohio. It's thought to be one of the most profitable shale plays in the entire country with possibly over 100 years worth of energy at current consumption rates. The sudden rush for drilling in the Marcellus Shale has been brought on by recent technological developments in hydraulic fracturing and horizontal drilling. Since 2005 when Range Resources drilled it's first exploratory well in Western PA there has been an exponential increase in drilling.

Slide 7



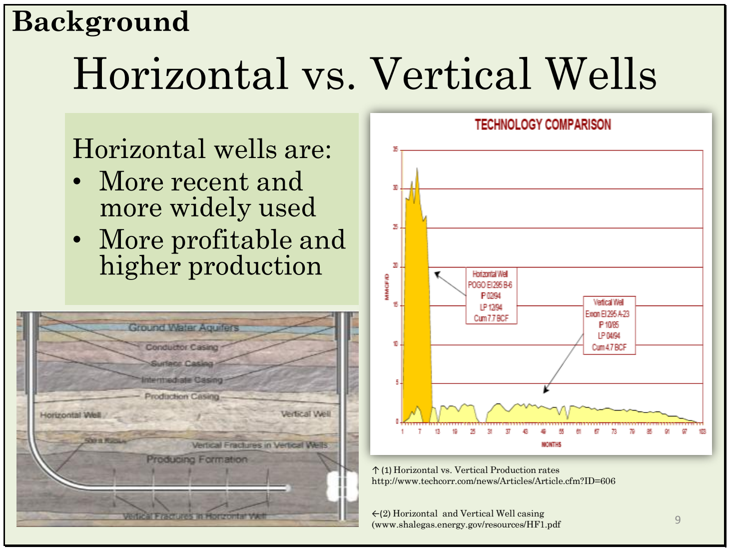
The process of harvesting natural gas begins with site investigation. Aerial surveillance photography is used to determine if the regions geography is adequate for drilling. Then subsurface geology analyses are completed. One method is seismic analyses, shown in this image, this is completed when a small explosion is applied to the ground that sends out seismic waves. A sensitive receiver interprets these waves to get a better understanding of what formations are below ground. Magnetic analysis is another method of interpreting the underground formations. This consists of a magnetic field, which is applied to the formation, and an interpretation of variation in the rebounding waves. Once the site has been deemed promising an exploratory wells is drilled. Initial tests of the well including pressure and initial flow rates of the formation. If the company views the exploratory well as profitable then a wellhead is attached.

Slide 8



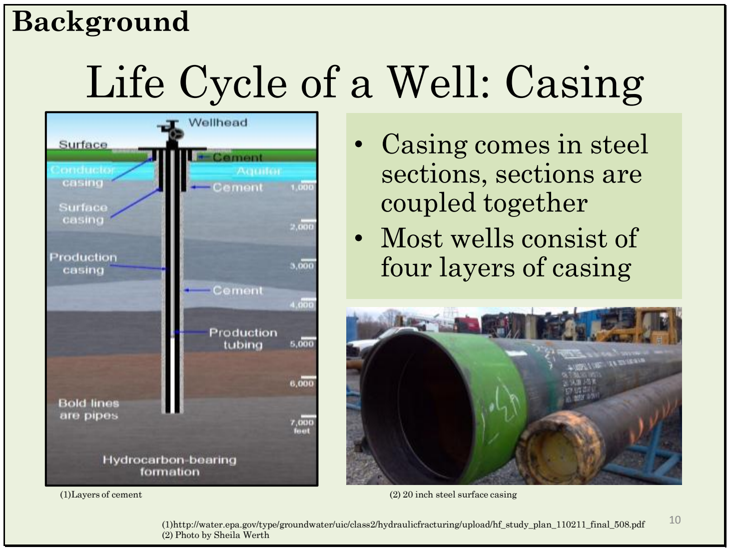
The process of drilling of a well can take up to one to two months. This process is completed using a drilling string, which is made up of the drill bit, which has tungsten carbide inserts. Next is drill collars, which are thick walled pipes, used provide weight and stability. Finally drill pipe is attached as the drill progress. These pipes carry the drilling mud, which is used to cool the bit and push away the pieces of rock.

Slide 9



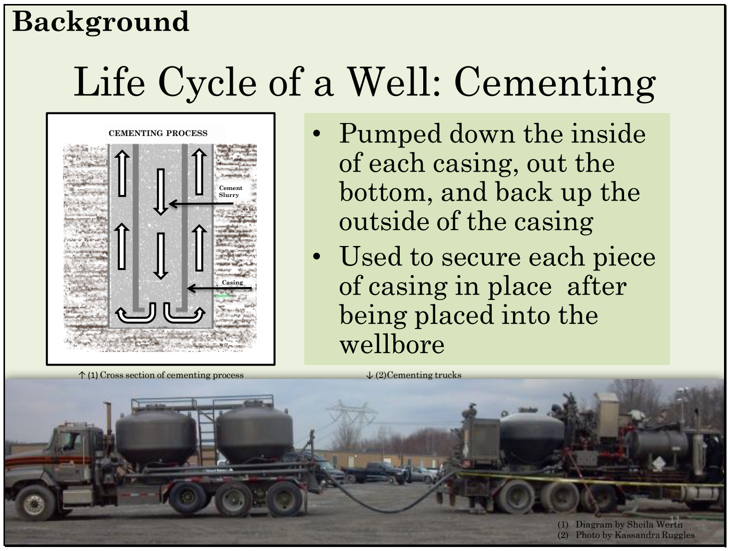
There are two types of wells that can be drilled, horizontal and vertical. Vertical wells in the Marcellus shale only access 50 feet of shale therefore horizontal wells are more typically used. Horizontal well construction is exactly the same as a vertical well until the kick off point, which is where the drill bit begins to turn and create the lateral section. This lateral portion can extend 6,000 feet. Therefore, horizontal wells have a higher production rate than a vertical well as seen in this graph.

Slide 10



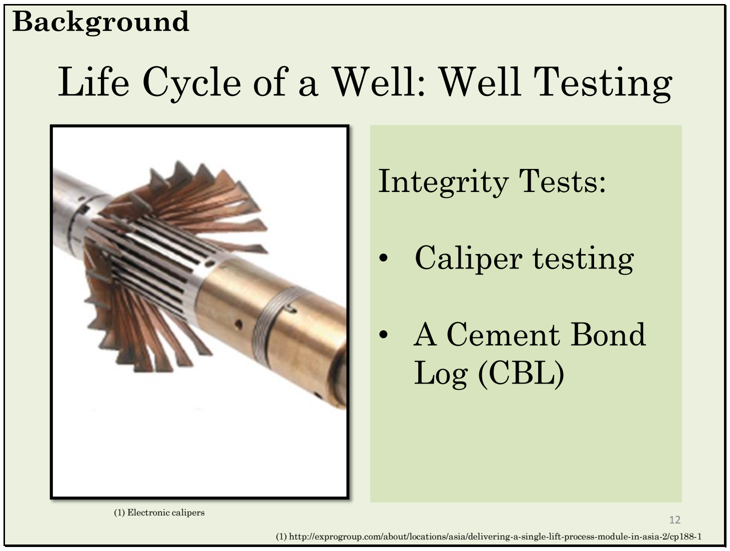
After the well has been drilled the casing must be put in place. The first section if the conductor casing which serves as a structural piling. The next is the surface casing, which isolates the well from an underground source of drinking water. The intermediate casing, which isolates the well from other formations such as coal. The final casing to be inserted is the production casing, which extends the entire length of the well.

Slide 11



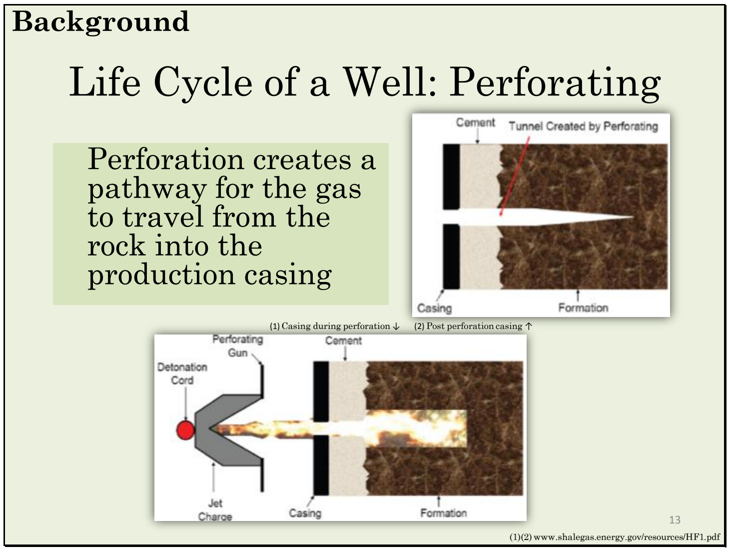
These casings are cemented in place after they have been put in place. The cement is mixed onsite in truck like those seen here. The first truck holds the cement powder, the second truck mixes the cement with water and pumps it at a high pressure into the well. The cement is pumped into the casing where it comes out of the bottom and back up into the annular space between the formation and the casing.

Slide 12



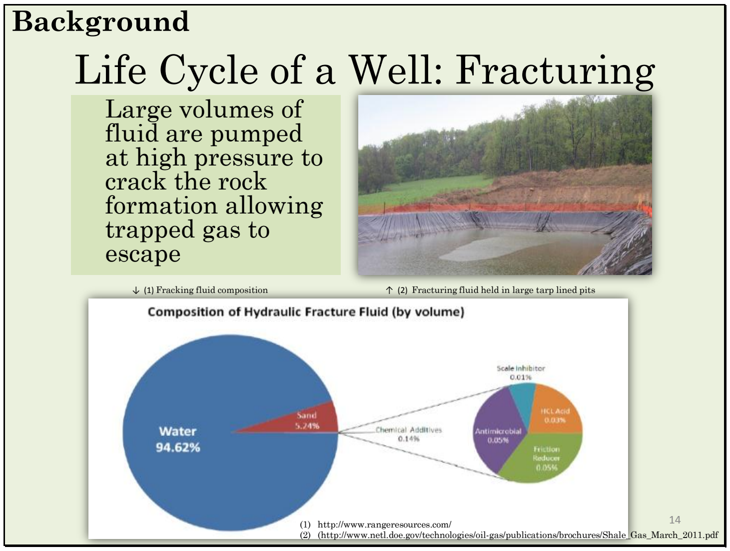
The integrity of the well must be determined. A caliper, seen here, is lowered into to the wellbore to measure the diameter of the hole. This is very important in cement calculations, this determines the amount of cement required. A cement bond log is created when an acoustic device lowered into the wellbore. The wavelengths are interpreted for impurities in the cement, such as incomplete isolation and channeling.

Slide 13



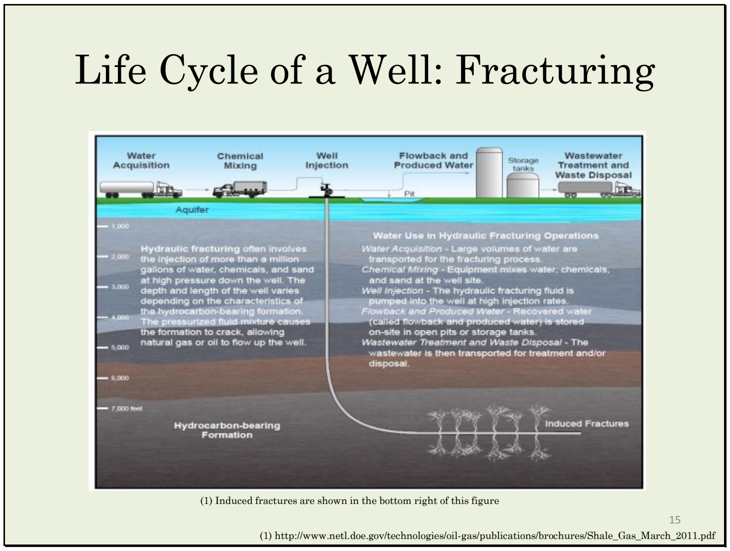
After the well has been tested perforation can begin. A detonation cord is lowered into the well and a small explosive charge creates a hole in the casing, cement, and the formation. The tunnel is created to allow hydraulic fluid access to the formation.

Slide 14



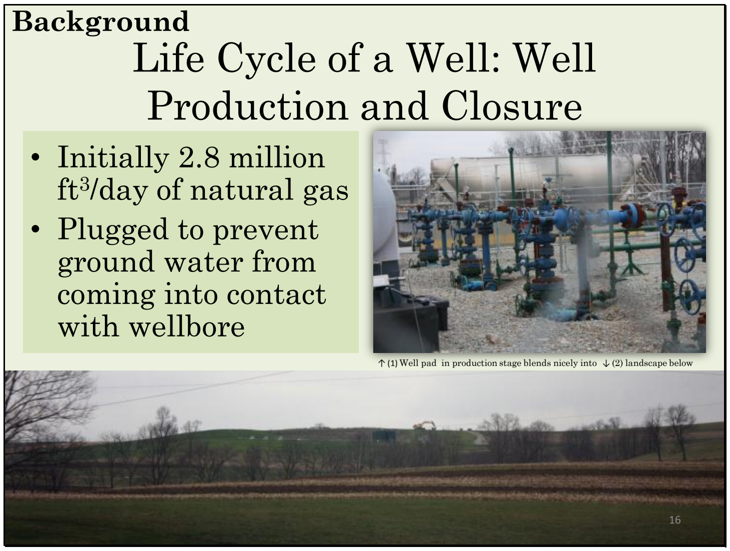
Hydraulic fluid is composed of mostly water with added sand and a very small amount of chemical additives. Companies store the large amount of water required in impoundments seen here.

Slide 15



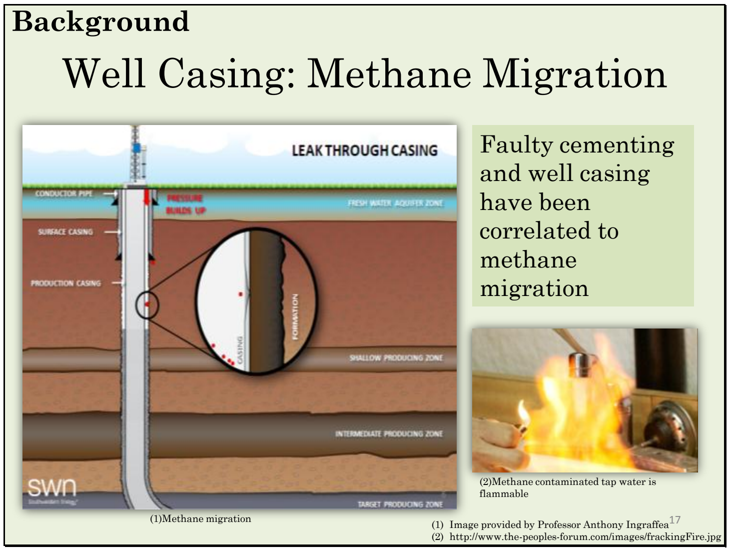
The hydraulic fracturing process begins with mixing the water with sand and other chemicals. The fluid is then injected into the well at a very high pressure. The fluid creates fractures in the formations and forces the sand into the shale pores. After the pressure is reduced the gas to rises up the wellbore. As the gas rises it carries hydraulic fluid, called flowback. This water can be recycled but needs to be properly treated.

Slide 16



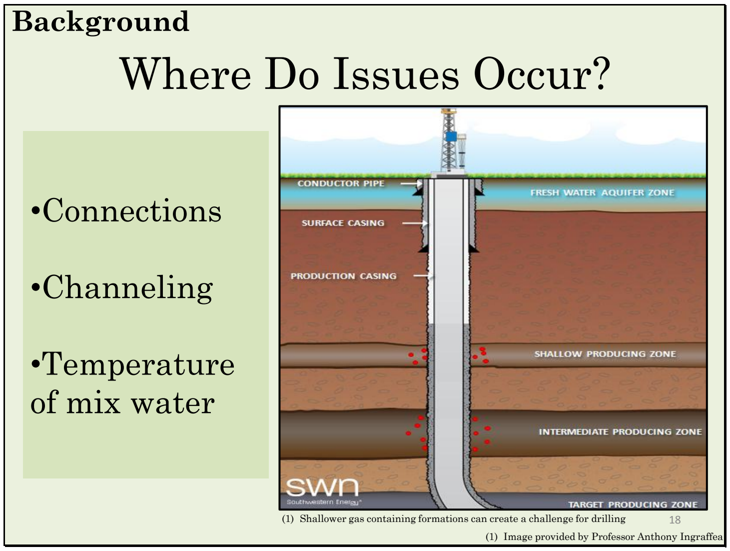
A typical Marcellus well produces 2.8 million cubic feet per day of natural gas. This picture shows a production pad located in rural Pennsylvania. After the well no longer produces an economical amount of gas it is plugged and capped to prevent ground water coming in contact with the wellbore.

Slide 17



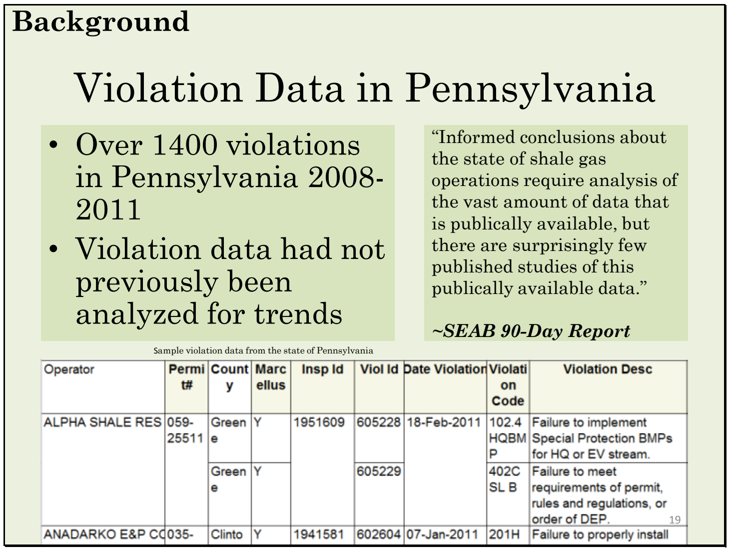
According to Pennsylvania's Acting Deputy Secretary of Oil and Gas Management, Scott Perry, Methane Migration is the most serious issue related to shale gas extraction. Methane migration occurs when an incomplete seal around the well casing allows gas to move towards the surface and possibly contaminate drinking water or the atmosphere.

Slide 18



Issues can arise at a number of different places throughout the well bore. One of the places is at the connections between the sections of casing. Although these connections only account for about three percent of the total length, approximately ninety percent of casing failures occur at these joints. Also, the effects of drilling through shallower gas bearing formations must be taken into account. As the cement is being poured, gas can leak out from these formations and create channels in the cement, which can act as a pathway for methane migration.

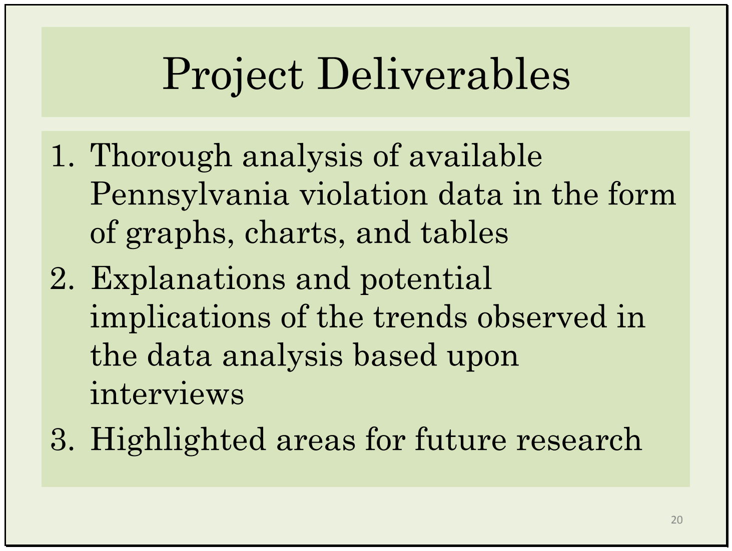
Slide 19



Operator	Permit#	County	Marcellus	Insp Id	Viol Id	Date Violation	Violation Code	Violation Desc
ALPHA SHALE RES	059-25511	Greene	Y	1951609	605228	18-Feb-2011	102.4 HQBMP	Failure to implement Special Protection BMPs for HQ or EV stream.
		Greene	Y		605229		402C SL B	Failure to meet requirements of permit, rules and regulations, or order of DEP.
ANADARKO E&P CO	035-	Clinto	Y	1941581	602604	07-Jan-2011	201H	Failure to properly install

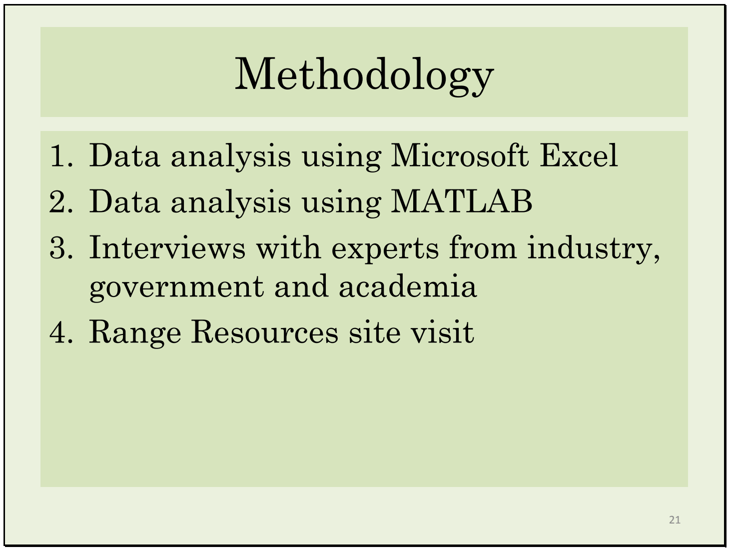
The data as shown above by a snap shot, are state violations that have been issued between 2008 and 2011. Although there are over 1400 violations, they have yet to be analyzed until now. As prescribed by the SEAB 90-Day report the feeling is that it's necessary to examine this data to obtain informed conclusions.

Slide 20



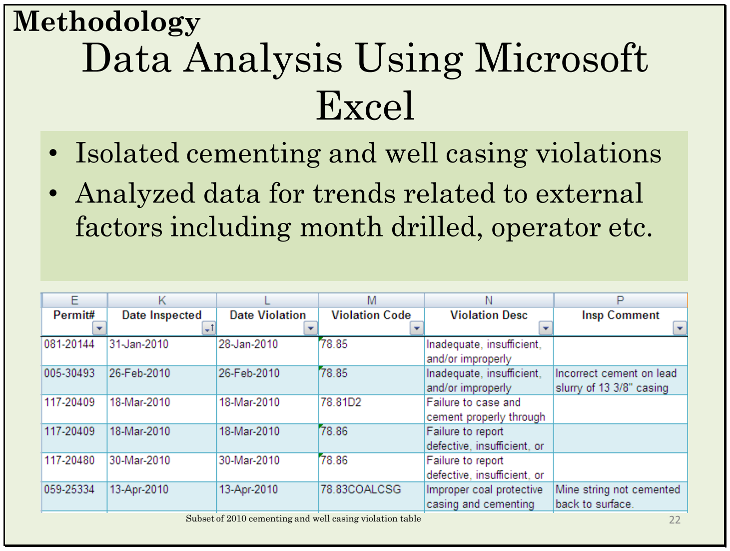
In the end, the deliverables of our project include an analysis of Pennsylvania violation data from graphs, charts, and tables. We also were able to obtain explanations and potential implications of the trends observed in the data from interviews with experts. Most importantly, we have found area's for future research to be performed.

Slide 21



To accomplish our deliverables, we broke down our methodology into 4 main components. First two parts of methodology address data analysis, part 1 using excel, and part 2 using MATLAB. To explain trends that we observed we conducted interviews and completed a Range Resources site visit.

Slide 22

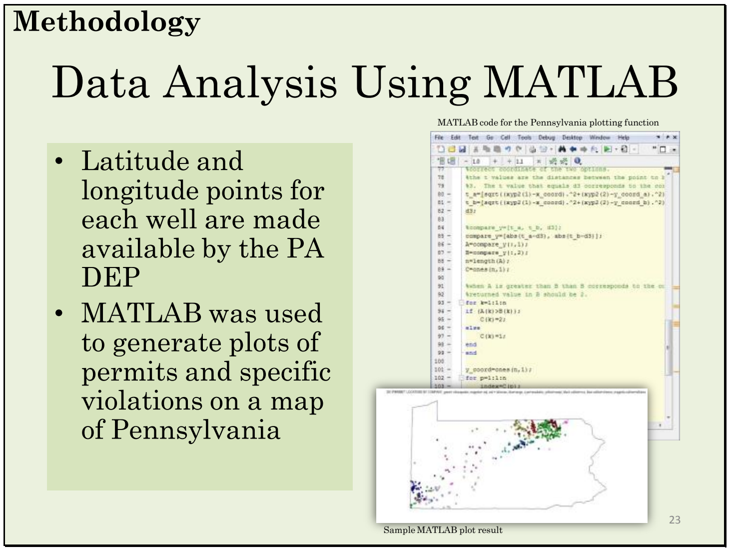


E	K	L	M	N	P
Permit#	Date Inspected	Date Violation	Violation Code	Violation Desc	Insp Comment
081-20144	31-Jan-2010	28-Jan-2010	78.85	Inadequate, insufficient, and/or improperly	
005-30493	26-Feb-2010	26-Feb-2010	78.85	Inadequate, insufficient, and/or improperly	Incorrect cement on lead slurry of 13 3/8" casing
117-20409	18-Mar-2010	18-Mar-2010	78.81D2	Failure to case and cement properly through	
117-20409	18-Mar-2010	18-Mar-2010	78.86	Failure to report defective, insufficient, or	
117-20480	30-Mar-2010	30-Mar-2010	78.86	Failure to report defective, insufficient, or	
059-25334	13-Apr-2010	13-Apr-2010	78.83COALCSG	Improper coal protective casing and cementing	Mine string not cemented back to surface.

Subset of 2010 cementing and well casing violation table

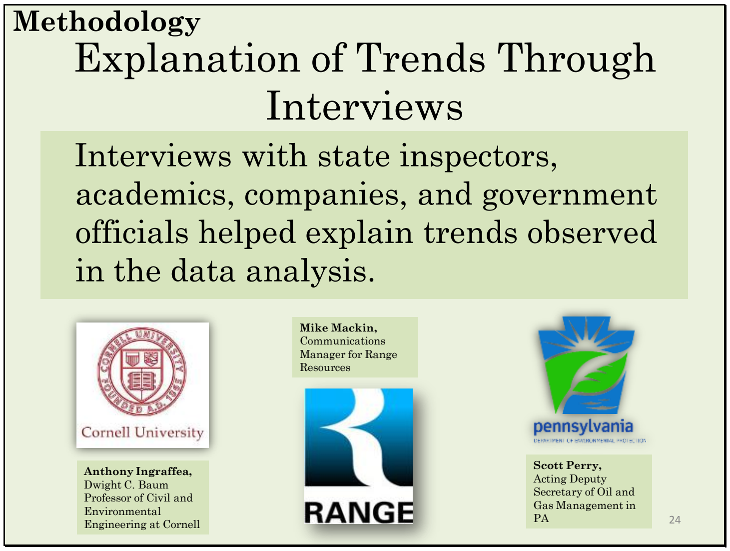
The raw data provided included a number of non cementing and well casing violations that we removed from the list. We also removed entries that we considered duplicates. The figure shows a sample of the remaining data. Once we had a spreadsheet of violations for each year, we used Excel functions to examine the data for trends.

Slide 23



State permit data contains latitude and longitude coordinates for each well. The violation spreadsheets contain a permit number for the specific violation that allowed us to look up the lat/long coords of that specific violation in the permit data spreadsheet. The MATLAB code that we wrote consumes the lat/long data and plots the points on the map of PA. If there are any questions on how to use this code to generate more plots, contact Sheila Werth (sheila.werth@wpi.edu) . The code is included in our paper appendix.

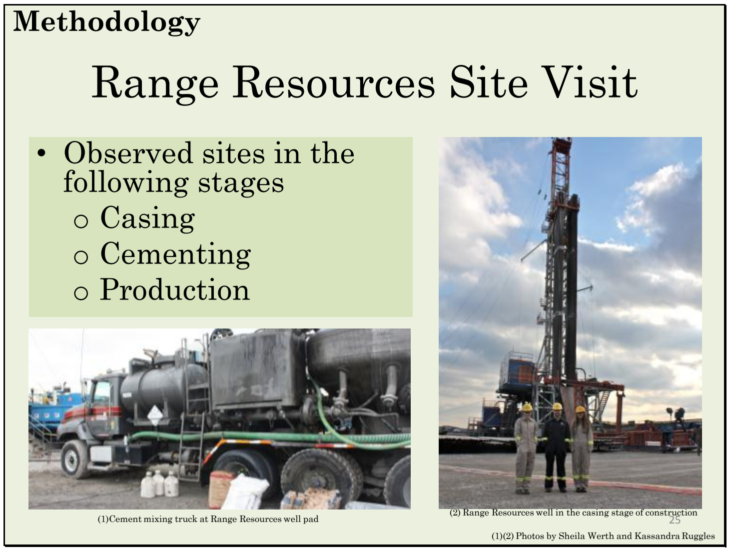
Slide 24



We conducted interviews with people who were experts in the field. Some of the most helpful were:

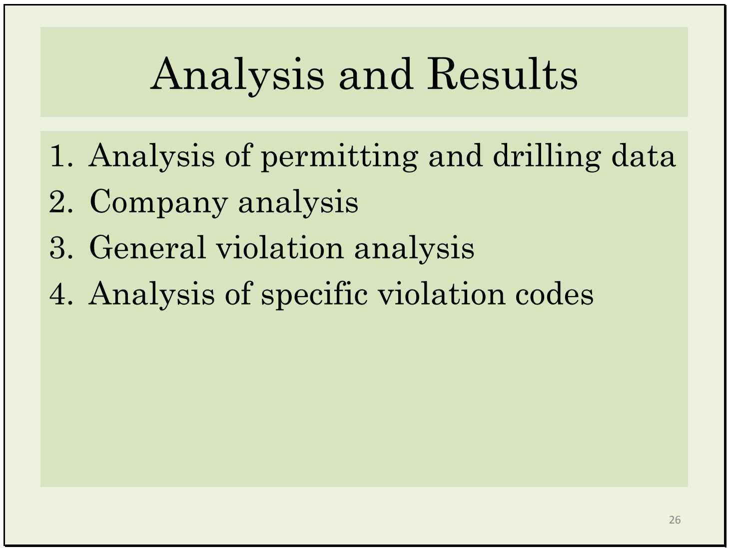
- Prof. Ingraffea, world renowned fracking expert. Technical insight on cementing and well casing
- Mike Mackin, told us about Range safety procedure and put us in touch with a petroleum engineer
- Scott Perry, told us about the problems with the data as well as the biggest challenges that PA is facing.

Slide 25



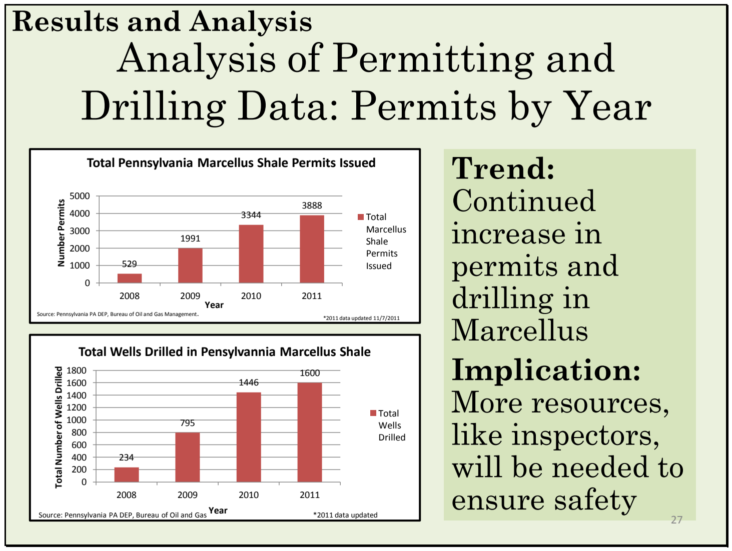
Range site visit, we saw three different sites.
-Figure on right: site in casing stage, they were lowering casing and we watched
-Figure on bottum left: cementing truck at site two, this site was in the cementing stage
-We also saw a site in production and this photo was used on slide 16. We have all of our other site visit photos as well, don't hesitate to email about that!

Slide 26



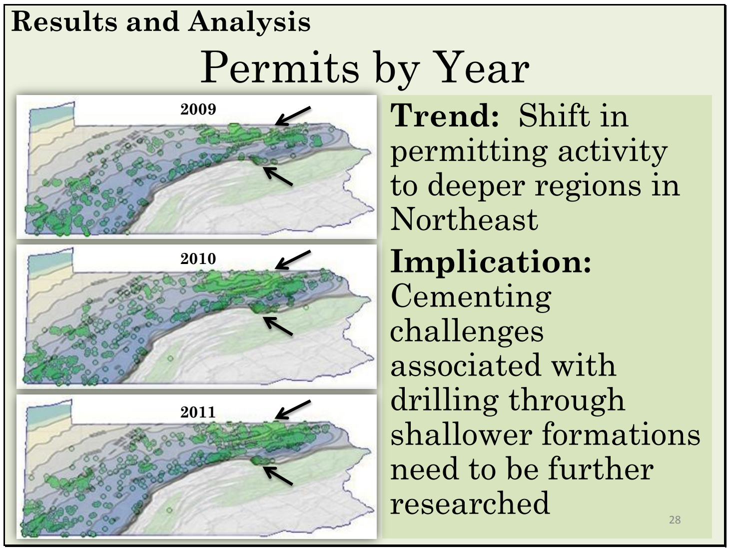
Our analysis and results can be broken down into the following umbrella topics: …………

Slide 27



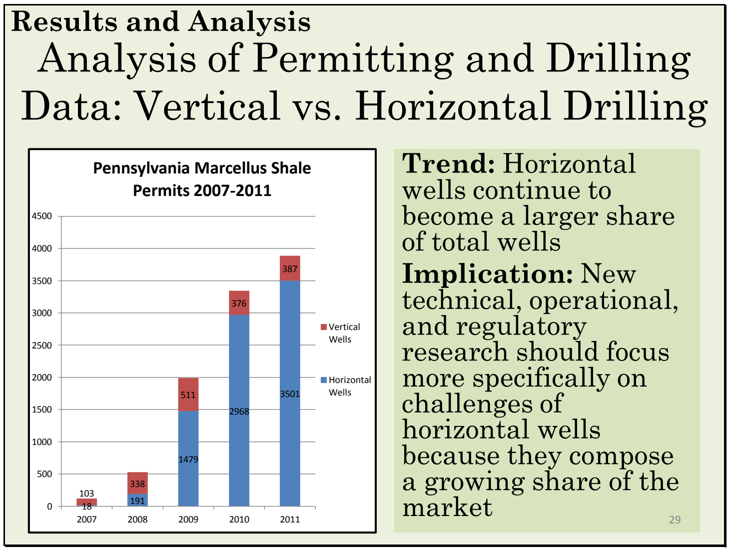
-can see general trend of growth
-more permits than wells drilled, sometimes a company will secure a permit and drill on it 1-2 yrs later, sometimes they wont drill on it at all. Regardless, both are growing so resources that help ensure safety need to be ramped up

Slide 28



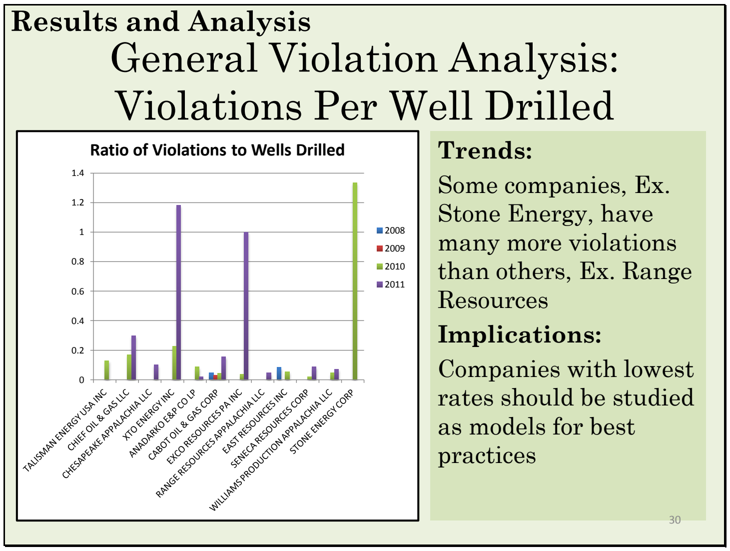
This is another way of looking at the growth of the industry in pa. Green dots are permits. Underlay shows depth. Darker colors are deeper areas. Areas pointed out by arrows show where there has been the most growth. These areas are also where there are shallower gas containing formations so the challenges here need to be further researched.

Slide 29



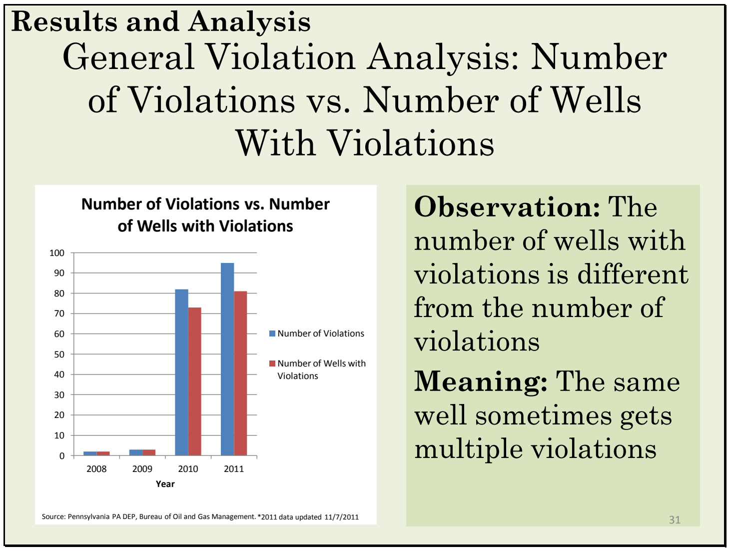
Horizontal wells are growing share of the market and growing in general. Need more research!

Slide 30



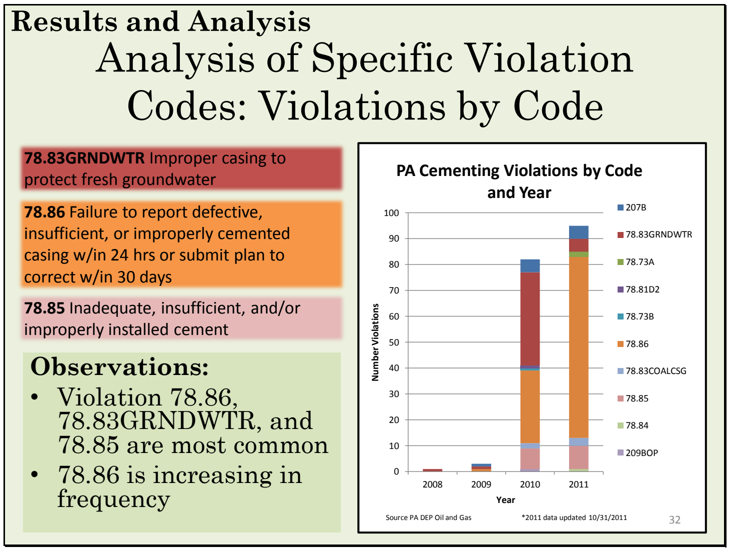
This graph shows the ration of cementing and well casing violations to the number of wells drilled by certain companies in the years 2008 to 2011. Some companies (XTO, EXCO, STONE) had a very high ration of violations to wells drilled for certain years. Other companies (RANGE RESOURCES) had a very low ratio of violations. Communication and cooperation between companies is necessary to inform best practices and advance safe and sustainable drilling.

Slide 31



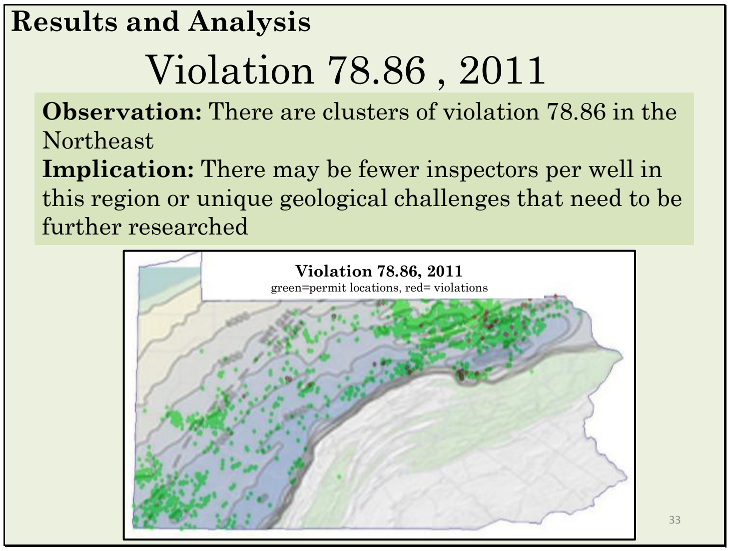
This graph shows the number of violations issued in a certain year with relation to the number of wells that received violations. In 2010 and 2011, a number of wells received multiple violations.

Slide 32



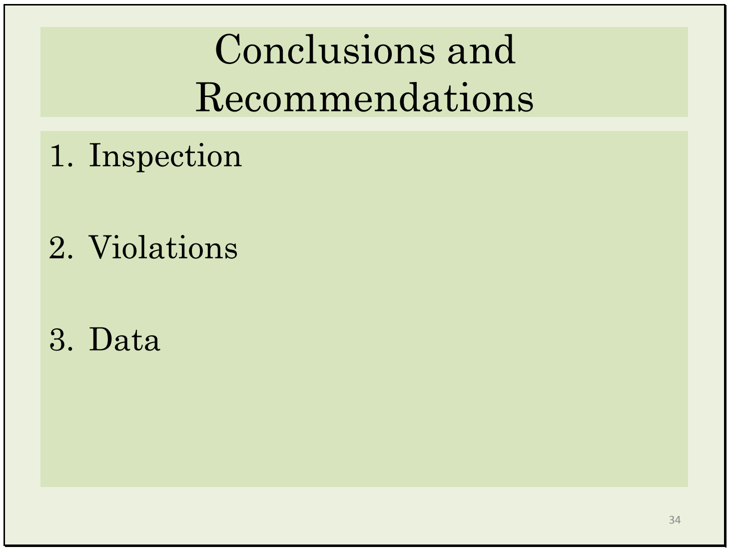
This graph shows the distribution of cementing and well casing violations in Pennsylvania for the years 2008 to 2011. In 2011, violation 78.86 was by far the most common violation issued. Violation 78.86 is issued for failure to report defective or improperly cemented casing.

Slide 33



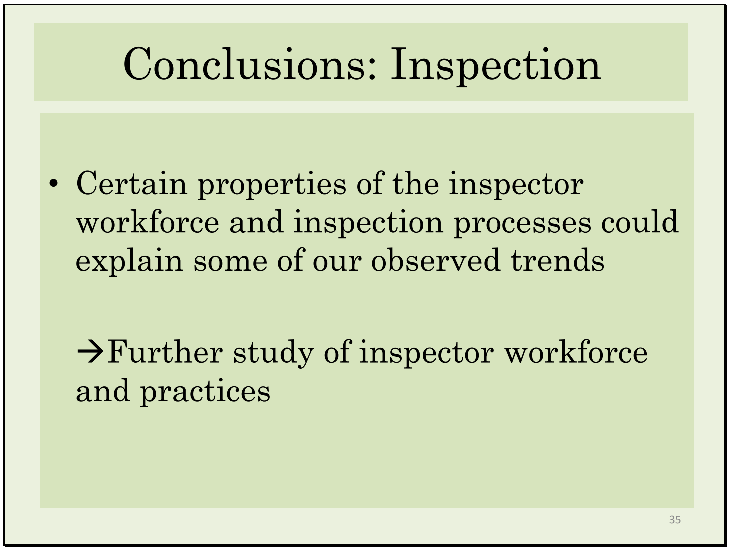
This graph shows the geographical distribution for violation 78.86 in 2011. The majority of violations can be found in the northeast and north-central regions of the state. This could be due to a higher concentration of shallower gas bearing formations in that region.

Slide 34



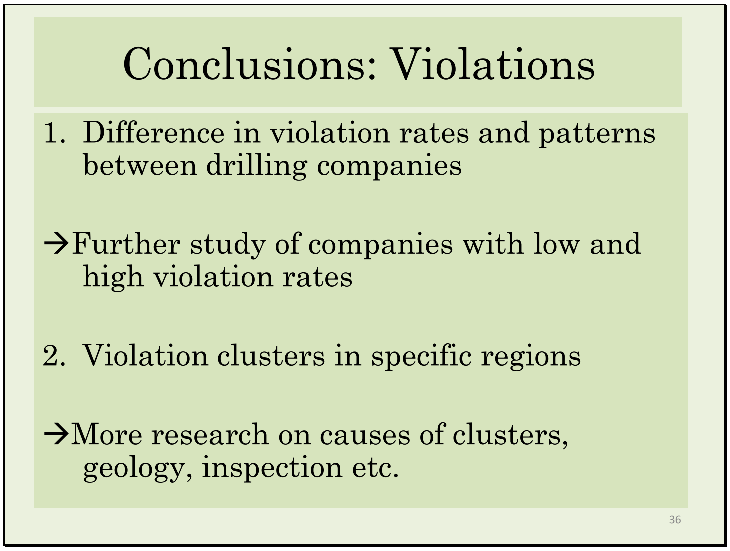
Our conclusions are broken up into three main categories: Inspection, Violations, and Data

Slide 35



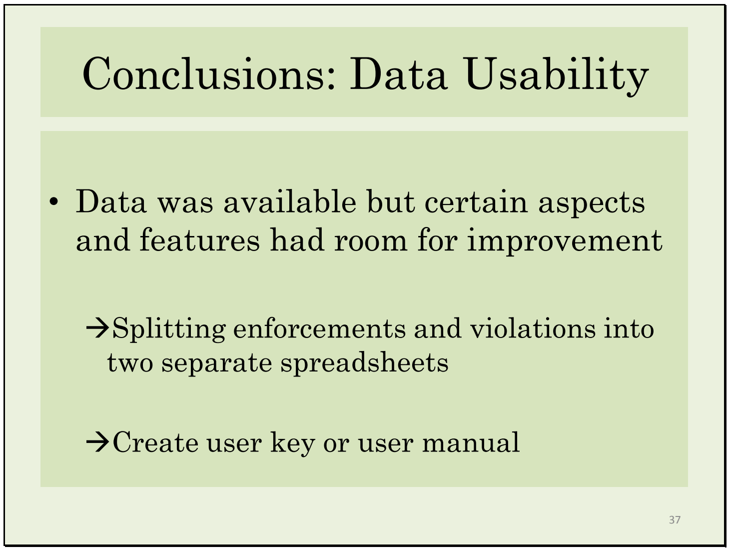
With regards to the inspection process we found that the inspectors were not evenly distributed throughout the state. Also, the process for choosing sites for inspection could possibly be improved by using a targeted or “smart” selection process.

Slide 36



With regards to violations, we found that companies had different rates of violation and cooperation and communication of best practices will help advance the industry in a safe way. Also, we found that violations tended to occur more often in specific regions and more research will need to be done in order to identify a definitive cause.

Slide 37



By using the data management system for Pennsylvania, we noticed ways in which the presentation of the data could be improved. The separation of violations and enforcements into different spreadsheets, the inclusion of a search tool, and the addition of a user manual would make the data easier to use.

Slide 38

At this time we would like to thank Professors Mustapha Fofana and Joshua Rosenstock from WPI. They have been helpful and supportive, in every sense, through each stage of this project. Also, Diana and Kevin from the DOE generously gave their time to provide us with valuable advice, guidance, and countless resources to foster our creativity and help us complete our project. At the DOE, we were made to feel welcome and supported by every employee we came into contact with. Specifically, we would like to thank Brandon Knight for taking us under his wing. We would also like to thank Al Cobb for his involvement in our project, the steady supply of relevant reading material, and an unforgettable Capital tour.

Slide 39


Questions/Comments?
Contact Information:
(DCDOE@wpi.edu)
»Steven Deane-Shinbrot
»Kassandra Ruggles
»Griffin Walker
»Sheila Werth
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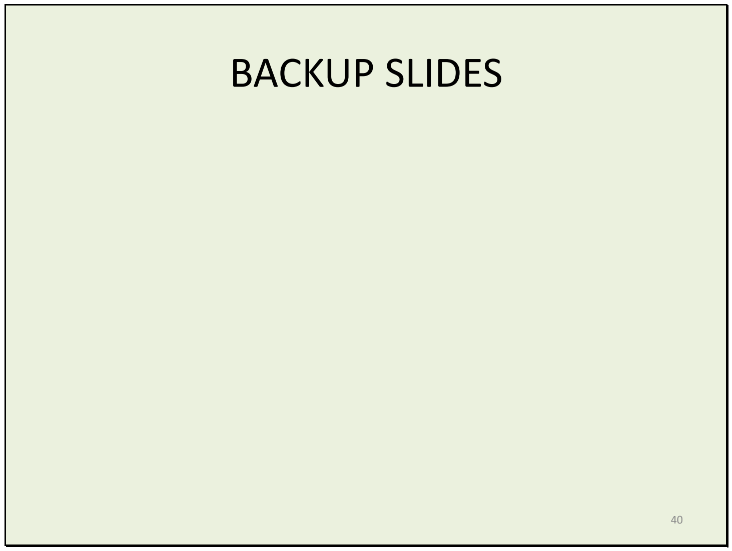
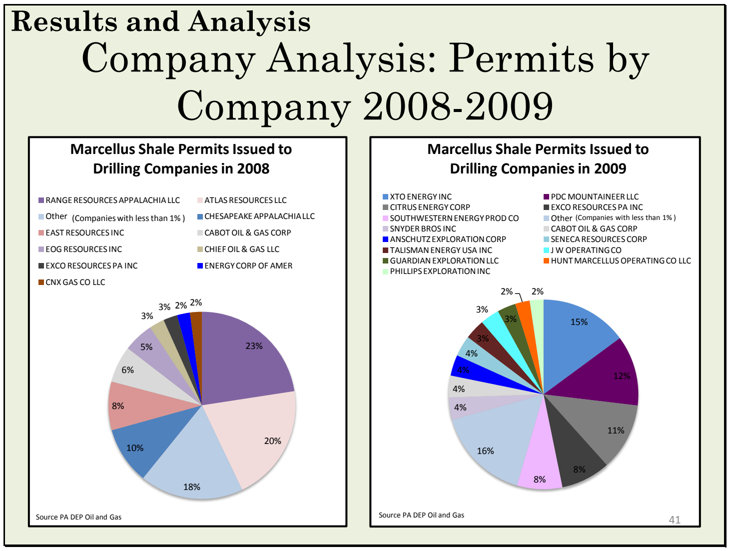
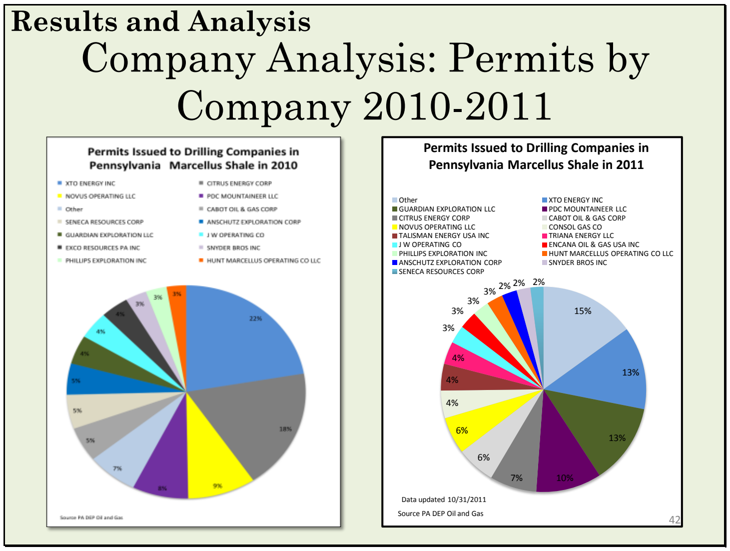
Slide 40



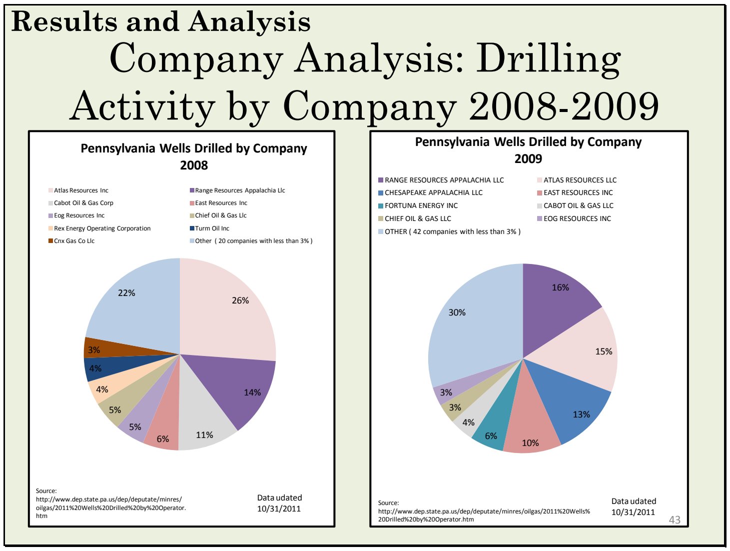
Slide 41


Results and Analysis
Company Analysis: Permits by Company 2008-2009
Marcellus Shale Permits Issued to Drilling Companies in 2008
RANGE RESOURCES APPALACHIA LLC
ATLAS RESOURCES LLC
Other (Companies with less than 1%)
CHESAPEAKE APPALACHIA LLC
EAST RESOURCES INC
CABOT OIL & GAS CORP
EOG RESOURCES INC
CHIEF OIL & GAS LLC
EXCO RESOURCES PA INC
ENERGY CORP OF AMER
CNX GAS CO LLC
23%
20%
18%
10%
8%
6%
5%
3%
3%
2%
2%
Source PA DEP Oil and Gas
Marcellus Shale Permits Issued to Drilling Companies in 2009
XTO ENERGY INC
PDC MOUNTAINEER LLC
CITRUS ENERGY CORP
EXCO RESOURCES PA INC
SOUTHWESTERN ENERGY PROD CO
Other (Companies with less than 1%)
SNYDER BROS INC
CABOT OIL & GAS CORP
ANSCHUTZ EXPLORATION CORP
SENECA RESOURCES CORP
TALISMAN ENERGY USA INC
J W OPERATING CO
GUARDIAN EXPLORATION LLC
HUNT MARCELLUS OPERATING CO LLC
PHILLIPS EXPLORATION INC
15%
12%
11%
8%
8%
16%
4%
4%
4%
4%
3%
3%
3%
2%
2%
Source PA DEP Oil and Gas
41

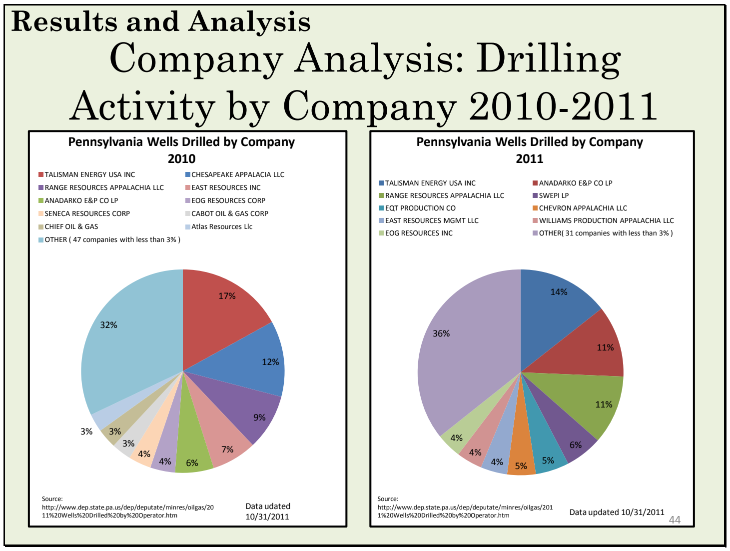
Slide 42


Results and Analysis
Company Analysis: Permits by Company 2010-2011
Permits Issued to Drilling Companies in Pennsylvania Marcellus Shale in 2010
XTO ENERGY INC
CITRUS ENERGY CORP
NOVUS OPERATING LLC
PDC MOUNTAINEER LLC
Other
CABOT OIL & GAS CORP
SENECA RESOURCES CORP
ANSCHUTZ EXPLORATION CORP
GUARDIAN EXPLORATION LLC
J W OPERATING CO
EXCO RESOURCES PA INC
SNYDER BROS INC
PHILLIPS EXPLORATION INC
HUNT MARCELLUS OPERATING CO LLC
Permits Issued to Drilling Companies in Pennsylvania Marcellus Shale in 2011
Other
XTO ENERGY INC
GUARDIAN EXPLORATION LLC
PDC MOUNTAINEER LLC
CITRUS ENERGY CORP
CABOT OIL & GAS CORP
NOVUS OPERATING LLC
CONSOL GAS CO
TALISMAN ENERGY USA INC
TRIANA ENERGY LLC
J W OPERATING CO
ENCANA OIL & GAS USA INC
PHILLIPS EXPLORATION INC
HUNT MARCELLUS OPERATING CO LLC
ANSCHUTZ EXPLORATION CORP
SNYDER BROS INC
SENECA RESOURCES CORP
15%
13%
13%
10%
7%
6%
6%
4%
4%
4%
3%
3%
3%
3%
2%
2%
2%
Data updated 10/31/2011
Source PA DEP Oil and Gas
42

Slide 43


Results and Analysis
Company Analysis: Drilling Activity by Company 2008-2009
Pennsylvania Wells Drilled by Company 2008
Atlas Resources Inc
Range Resources Appalachia Llc
Cabot Oil & Gas Corp
East Resources Inc
Eog Resources Inc
Chief Oil & Gas Llc
Rex Energy Operating Corporation
Turm Oil Inc
Cnx Gas Co Llc
Other (20 companies with less than 3%)
26%
14%
11%
6%
5%
5%
4%
4%
3%
22%
Source: http://www.dep.state.pa.us/dep/deputate/minres/oilgas/2011%20Wells%20Drilled%20by%20Operator.htm
Data udated 10/31/2011
Pennsylvania Wells Drilled by Company 2009
RANGE RESOURCES APPALACHIA LLC
ATLAS RESOURCES LLC
CHESAPEAKE APPALACHIA LLC
EAST RESOURCES INC
FORTUNA ENERGY INC
CABOT OIL & GAS LLC
CHIEF OIL & GAS LLC
EOG RESOURCES INC
OTHER (42 companies with less than 3%)
16%
15%
13%
10%
6%
4%
3%
3%
30%
Source: http://www.dep.state.pa.us/dep/deputate/minres/oilgas/2011%20Wells%20Drilled%20by%20Operator.htm
Data udated 10/31/2011
43

Slide 44


Results and Analysis
Company Analysis: Drilling Activity by Company 2010-2011
Pennsylvania Wells Drilled by Company 2010
TALISMAN ENERGY USA INC
CHESAPEAKE APPALACIA LLC
RANGE RESOURCES APPALACHIA LLC
EAST RESOURCES INC
ANADARKO E&P CO LP
EOG RESOURCES CORP
SENECA RESOURCES CORP
CABOT OIL & GAS CORP
CHIEF OIL & GAS
Atlas Resources Llc
OTHER (47 companies with less than 3%)
17%
12%
9%
7%
6%
4%
4%
3%
3%
3%
32%
Source: http://www.dep.state.pa.us/dep/deputate/minres/oilgas/2011%20Wells%20Drilled%20by%20Operator.htm
Data udated 10/31/2011
Pennsylvania Wells Drilled by Company 2011
TALISMAN ENERGY USA INC
ANADARKO E&P CO LP
RANGE RESOURCES APPALACHIA LLC
SWEPI LP
EQT PRODUCTION CO
CHEVRON APPALACHIA LLC
EAST RESOURCES MGMT LLC
WILLIAMS PRODUCTION APPALACHIA LLC
EOG RESOURCES INC
OTHER(31 companies with less than 3%)
14%
11%
11%
6%
5%
5%
4%
4%
4%
36%
Source: http://www.dep.state.pa.us/dep/deputate/minres/oilgas/2011%20Wells%20Drilled%20by%20Operator.htm
Data updated 10/31/2011
44

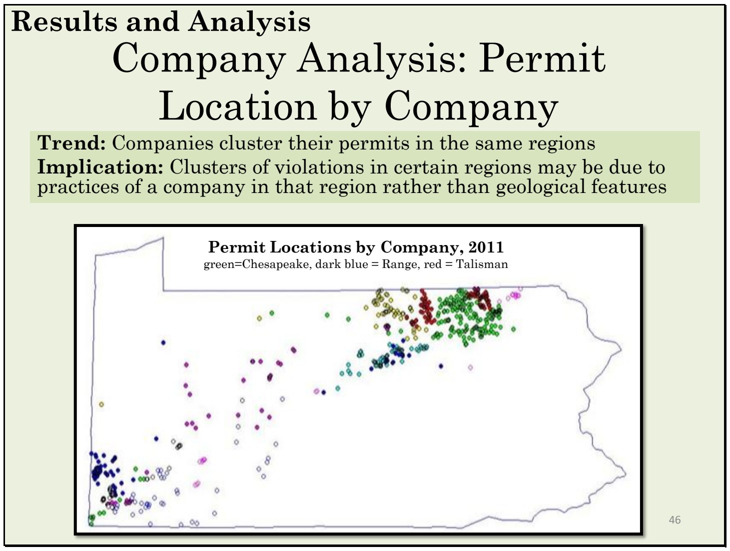
Slide 45

Violation Codes (cementing and well casing only)

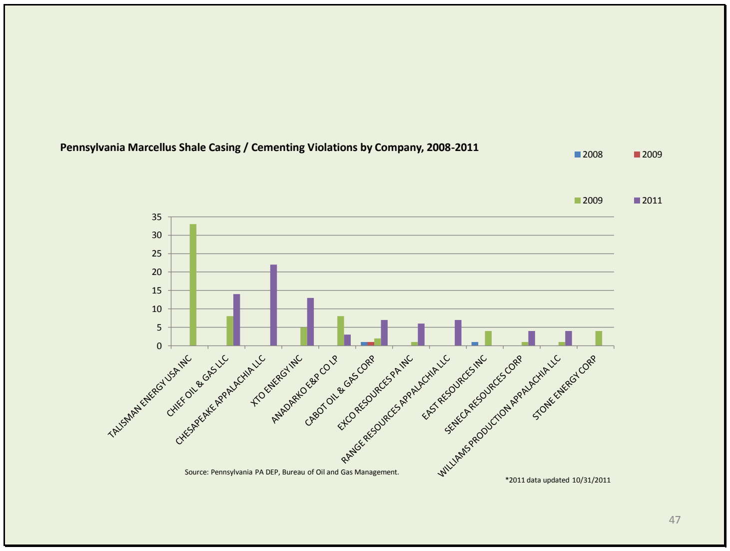
Code	Description
207B	Failure to case and cement to prevent migrations into fresh groundwater
78.83GRNDWTR	Improper casing to protect fresh groundwater
78.73A	Operator shall prevent gas and other fluids from lower formations from entering fresh groundwater.
78.81D2	Failure to case and cement properly through storage reservoir or storage horizon
79.12	Inadequate casing/cementing in conservation well
78.73B	Excessive casing seat pressure
78.86	Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days
78.83COALCSG	Improper coal protective casing and cementing procedures
78.85	Inadequate, insufficient, and/or improperly installed cement
78.84	Insufficient casing strength, thickness, and installation equipment
209CASING	Using inadequate casing
209BOP	Inadequate or improperly installed BOP, other safety devices, or no certified BOP operator
78.81D2PLAN	Failure to obtain proper approval for casing and cementing procedure for wells in storage and protective areas

45

Slide 46


Results and Analysis
Company Analysis: Permit Location by Company
Trend: Companies cluster their permits in the same regions
Implication: Clusters of violations in certain regions may be due to practices of a company in that region rather than geological features
Permit Locations by Company, 2011
green=Chesapeake, dark blue = Range, red = Talisman
46

Slide 47


Pennsylvania Marcellus Shale Casing / Cementing Violations by Company, 2008-2011
2008
2009
2009
2011
35
30
25
20
15
10
5
0
TALISMAN ENERGY USA INC
CHIEF OIL & GAS LLC
CHESAPEAKE APPALACHIA LLC
XTO ENERGY INC
ANADARKO E&P CO LP
CABOT OIL & GAS CORP
EXCO RESOURCES PA INC
RANGE RESOURCES APPALACHIA LLC
EAST RESOURCES INC
SENECA RESOURCES CORP
WILLIAMS PRODUCTION APPALACHIA LLC
STONE ENERGY CORP
Source: Pennsylvania PA DEP, Bureau of Oil and Gas Management.
*2011 data updated 10/31/2011
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Interviewee	Company/Agency	Title/division
Nateena Dobson	DOE-FE	Physical Scientist
Mike Dunn	EPA	Environmental Assessment and Innovation division
Christopher Knopes	EPA	Director National Planning, Measures, and Analysis
Roger A. Dietz	PA-DEP	IT Specialist
Ken Kennedy	PA-DEP	Inspector
Mike Panettieri	PA-DEP	Oil and Gas Inspector Supervisor
Scott Perry	PA-DEP	Acting Deputy Secretary of Oil and Gas Management
Dave Belcher	WV-DEP	Inspector Supervisor
Anthony R. Ingraffea	Cornell University	Civil and Environmental Engineering Professor
Nick Cerone	Range Resources	Petroleum Engineer
Mike Mackin	Range Resources	Communications Manager
Ronald Sweatman	Halliburton	Chief Technical Professional

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