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A GUIDE TO UNDERSTANDING THE MARCELLUS SHALE

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ABSTRACT

Extraction of natural gas from the Marcellus Shale of the Appalachian Basin is a hotly contested topic; it brings economic prosperity in a time of need, but poor management of associated environmental issues could leave lasting adverse human health effects. In August 2011, the United States Geological Survey estimated the quantity of recoverable natural gas in the Marcellus Shale at 70 trillion cubic feet. The Marcellus Shale is one of the largest shale deposits on Earth. With the exploitation of the shale comes the rebirth of industry in states such as Pennsylvania, West Virginia, and Ohio. In addition, shale gas is a reliable source of locally produced fuel that may foster independence from foreign oil; replacements from coal to natural gas-fired power plants have the potential to reduce carbon and other pollutant emissions. What caused the recent interest in the Marcellus was commodity price coupled with two technologies that made it financially attractive: horizontal drilling and hydraulic fracturing. Hydraulic fracturing produces over 500,000 gallons of wastewater per well, containing carcinogenic chemicals, heavy metals, radioactivity, and salt. This flowback fluid has a few disposal options: treatment at industrial wastewater treatment plants, beneficial reuse, or injection in deep wells. The tradeoff is found in the limited regulatory preparedness to deal with the rapid expansion of the industry in Pennsylvania. State and federal officials are in a position to amplify or mitigate these concerns. The purpose of this thesis is to determine if current legislation is adequate to safeguard residents from the potential adverse health effects of hydraulic fracturing, and to ensure the financial prosperity of Pennsylvania for generations to come. This thesis is intended a guide for readers with a limited understanding of the topic. To familiarize the reader, included is an overview of the geology, history, technology, fluid disposal options, and water quality concerns associated with drilling the Marcellus Shale.
Following is discussion on current and impending legislation regarding gas production both on the state and federal levels. Information was derived from research papers published by government agencies, academia, gas companies, activist groups, and coalition groups; ancillary information on human health effects was garnered from groups more distanced from the subject. It was found that the legislation may be sufficient to protect human health, as long as appropriate standards are set and subsequently followed. However, there is a stark imbalance between the number of inspection staff and volume of activity, so the enforceability of these standards comes into question. Moving forward, federal legislation requiring full disclosure of hydraulic fracturing chemicals and redefinition of hydraulic fracturing to be covered under the Safe Drinking Water Act would serve to further protect residents. It was also determined that Pennsylvania should implement a gas production tax similar to the ones found in 98% of other gas producing states. This legislation is critical to ensuring Pennsylvania's financial and environmental well-being.

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Chapter 1

Introduction

The Marcellus Shale is natural gas producing super field, a hot topic on a national level that catches the attention of industry leaders and environmentalists alike. It may be the source of concern for residents who wonder if current legislation is sufficient to safeguard from environmental damage and to ensure the continued prosperity of Pennsylvania.

The Marcellus surfaced within the past decade due to attractive prices coupled with advancements in horizontal drilling and hydraulic fracturing technology. From the influx of recent activity, it would appear that the shale's potential has only recently been discovered. However, the location and properties of the Marcellus have been documented for centuries. This thesis is separated into four chapters. Chapter 1 provides a synopsis of the Marcellus Shale's history, geology, and geography, as well as an examination of markets for natural gas. Building on that information, Chapter 2 explains the technology involved in extracting natural gas from the Marcellus Shale: horizontal drilling and hydrofracturing. Chapter 3 outlines the potential environmental impacts of disposal options for waste fracturing fluid. Chapter 4 looks at federal and state legislation, current and proposed, dealing with environmental and fiscal matters. The compiled information hopes to provide a resident unfamiliar with the Marcellus Shale a basis of knowledge on which to make educated decisions.

1.1 Geology

The Marcellus Shale was deposited over 350 million years ago, when the present Appalachian Mountains were beneath a shallow sea.. What makes the Marcellus rich in hydrocarbons is the amount of organisms and plant matter that were deposited in the silty bottom layers of this sea. This organic material was covered by more Devonian age silts and compressed by overlying sedimentary rocks over millions of years to form the Marcellus Shale. See Figure 1.1a for a map of the Appalachian Basin overlaid with current state boundaries This map shows that the Marcellus Shale encompasses a large portion of Pennsylvania, West Virginia, New York, Ohio, Maryland, Kentucky, and Tennessee.

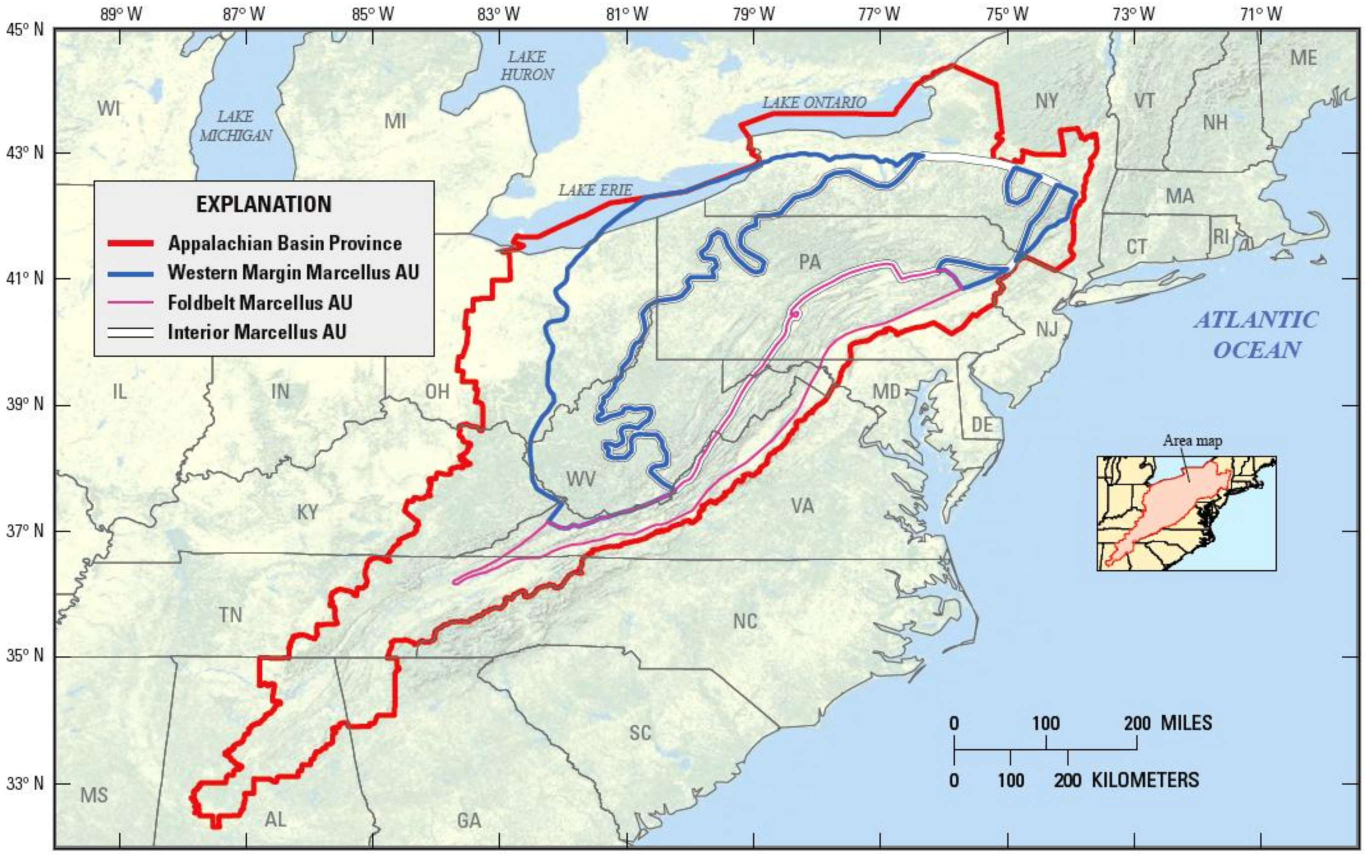


Figure 1.1a: Map of the Appalachian Basin, Marcellus Shale Formation
Source: USGS, 2011.

The Marcellus Shale is just one of many large shale basins present in the United States; other formations include the Barnett Shale (Texas), the Bakken Shale (North Dakota), and the Fayetteville Shale (Wyoming). The Energy Information Administration provides Figure 1.1b, showing shale deposits in North America.

Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI.
Updated: May 9, 2011

Figure 1.1b: North American Shale Plays (as of May 2011)
Source: Energy Information Administration, 2011.

The Marcellus Shale was deposited in a wedge shape, and varies in depth from east to west. The depths of the Marcellus Shale over the mid-Atlantic region range from 3,000-5,000 feet in Ohio, to over 8,000 feet in Pennsylvania.

In agreement with this data, the average depth of a Marcellus Shale well is about 5,300 feet (Chesapeake Energy 2011). For reference, that is the length of over four Empire State Buildings stacked end to end. The thickness of the majority of the shale varies from 100 to 250 feet, and is thickest in Northeastern and Southwestern Pennsylvania. Figure 1.1c, assembled by the Eastern Gas Shales Project, is provided showing the thickness of the shale throughout Pennsylvania.

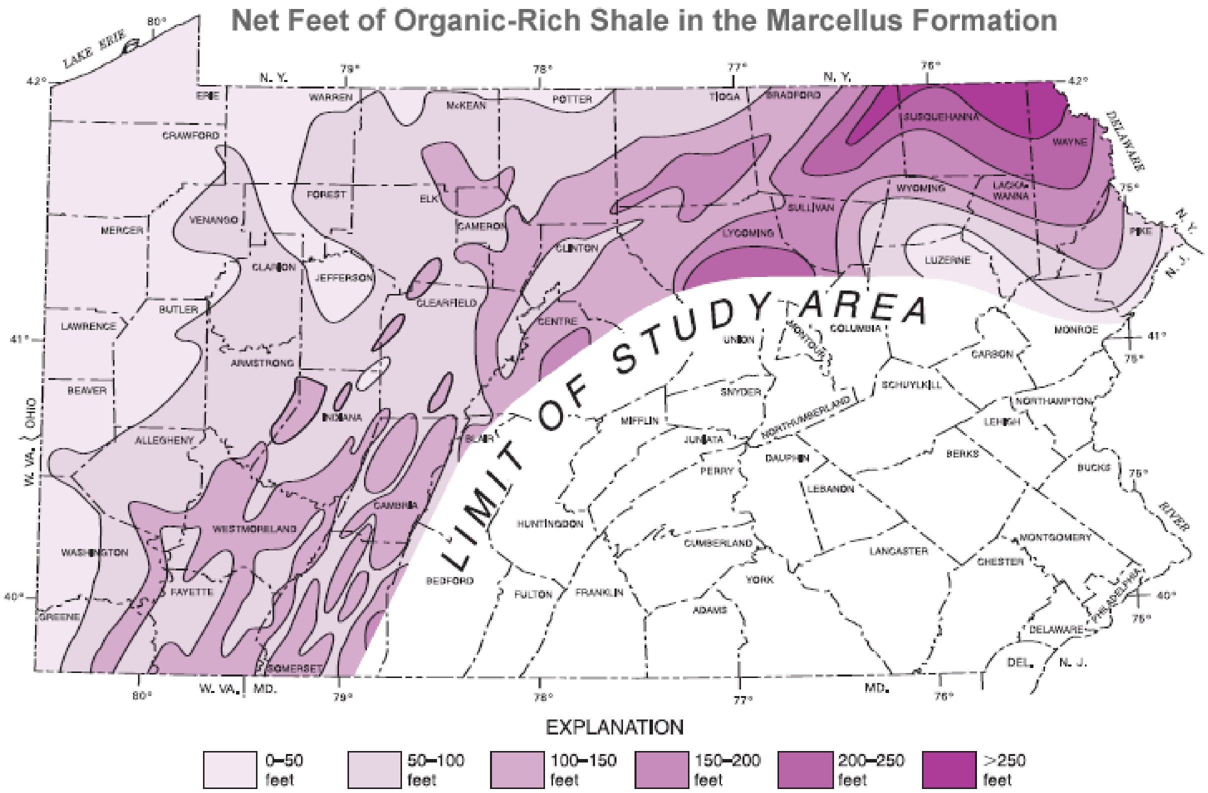


Figure 1.1c: Thicknesses of Organic Rich Marcellus Shale in Pennsylvania
Source: EGSP, 2011.

A distinct correlation exists between the thicknesses of organic rich shale and the permits issued by the Pennsylvania Department of Environmental Protection (DEP). Figure 1.1d compiled by the DEP's Bureau of Oil and Gas Management shows the well permits issued in 2010. There were 3,314 permits issued for drilling the Marcellus Shale only. The most active areas are in Northeastern and Southwestern Pennsylvania. Figure 1.1d, published by the Energy Information Administration shows that the Northeastern portion of Pennsylvania has pulled far ahead of other portions of the state, West Virginia, and the rest of the Northeast.

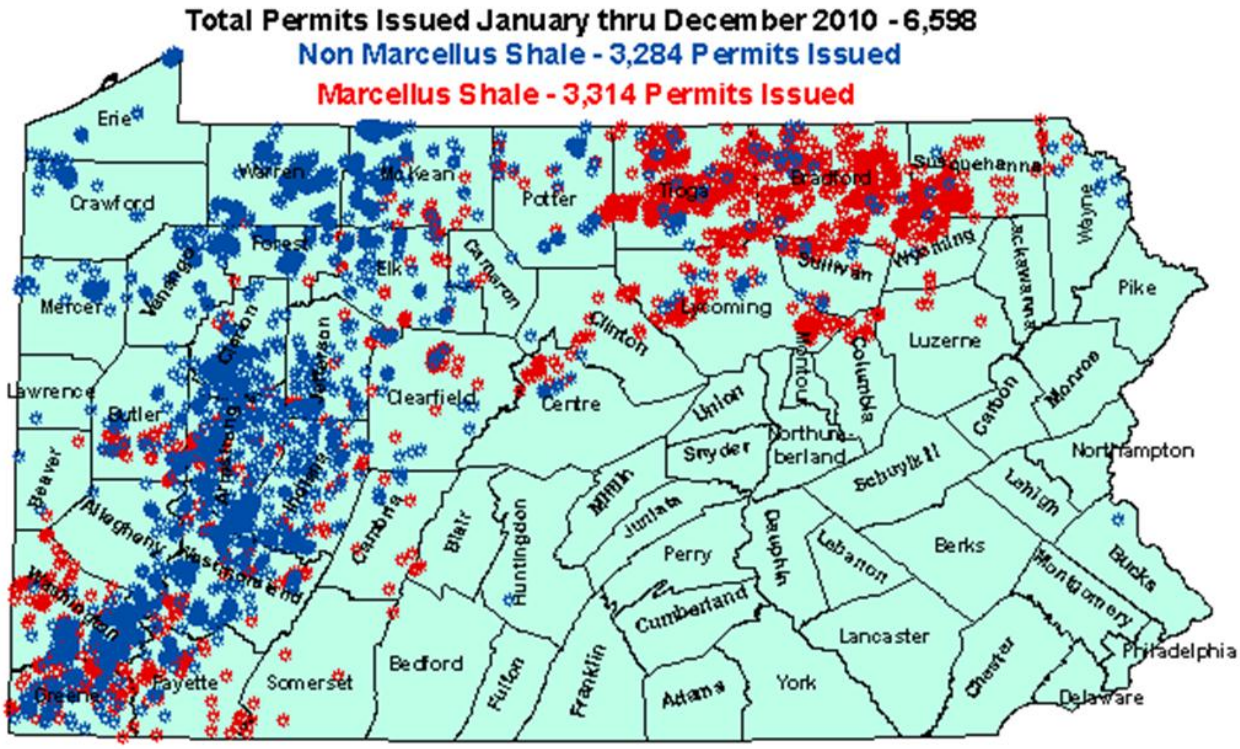


Figure 1.1d: Well Permits Issued

Source: Department of Environmental Protection, Bureau of Oil and Gas Management, 2011.

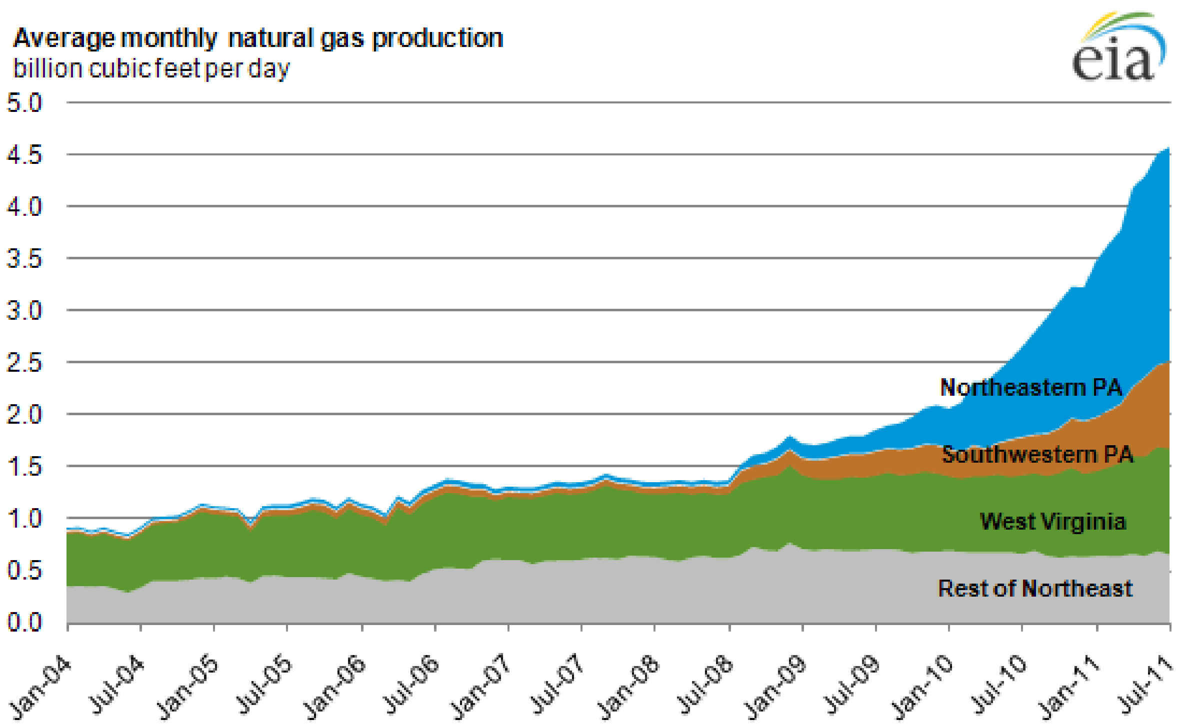


Figure 1.1e: Production Rates: Pennsylvania, West Virginia, and Rest of Northeast

Source: Energy Information Administration, 2011.

1.2 Discovery

Natural gas production in the Appalachian Basin has occurred for centuries. The city of Fredonia, New York along Lake Erie is home to the first commercial natural gas well in the northeast region. In 1821, residents noticed gas bubbling up from Canadaway Creek and gathered it to burn for lighting and heat. For chronological reference, this occurred 28 years before Sir Edwin Drake's first commercial oil well in Titusville, PA was drilled in 1849. The Appalachian Basin has a rich history in natural gas and oil – not just coal.

As early as the 1930's, oil and gas companies were exploiting commercially significant and predictable flows of natural gas in the Oriskany Sandstone formation beneath New York and Pennsylvania (Pennsylvania Geology 2008). The Oriskany Sandstone is located deeper than the Marcellus Shale and has a higher permeability, so traditional vertical drilling created sufficient pressure differentials for gas production.

To reach target depth in the Oriskany, their drills penetrated the Marcellus Shale. Operators were fascinated by what happened when they reached the layer of Marcellus: they experienced a burst of high natural gas production. These deluges of gas were so immense that wells shut down for several days when the borehole reached the Marcellus. It was a common occurrence, an anticipated delay in the schedule to reach the Oriskany, and they learned to ignore it. Certainly, if there were a way to keep sustained flow from this high-producing rock, they would have stopped there. More advanced methods are required for shale gas production and are outlined in Chapter 2.

1.3 Eastern Gas Shales Project

The Marcellus remained ambiguous until the Energy Crisis in 1970's, when the United States Department of Energy funded the Eastern Gas Shales Project (EGSP). This project funded teams of petro geologists, engineers, and other earth scientists to identify and map the shale plays in the Appalachian and Michigan Basins; the data produced by the EGSP in the 1970's still serves the industry today as knowledge base. Until the recent outbreak of scientific exploration of the Marcellus, it was the most comprehensive public data on the potential of this resource.

Not only did the EGSP scientists locate and categorize shales such as the Marcellus, they researched innovative techniques to extract the gas. Had the new technology received continuous funding from the U.S. Government in the 1970's, the Marcellus Shale might have already reached its peak production by 2011. The Department of Energy abandoned the EGSP project in the 1980's as it deemed the shale unlikely to produce sustained flow. The Energy Crisis subsided when the price of oil dropped again. The pressure was no longer on the United States to secure alternative sources of energy, so the Marcellus remained ambiguous for two more decades.

1.4 Current Events

In 2002, The United States Geological Survey estimated the recoverable natural gas in the Marcellus Shale at 1.9 Trillion Cubic Feet (TCF). This was prior to the realization that Marcellus could be exploited by horizontal drilling and hydraulic fracturing. The USGS issued a revised estimate in 2011, which increased the total recoverable reserves to 87 TCF. Range Resources is quoted saying “The Marcellus now appears to be the second or third largest natural gas play ever discovered in the world.” That is an unmistakable endorsement, which can be backed up by Range investing 86% of its 2011 capital budget to its Marcellus Division (2011).

Modern activity in the Marcellus Shale began in late 2003. Oil and gas company Range Resources Appalachia, LLC drilled a test well called Renz #1 in the southwest corner of Pennsylvania, in Washington County. The initial well site location is telling, as the southwest and northeast corners of Pennsylvania continue to lead the state’s production. Range drilled a similar formation in Texas called the Barnett Shale, where they piloted their horizontal drilling and hydraulic fracturing technique. Information explaining horizontal drilling and hydraulic fracturing can be found in Chapter 2.

The current situation has some parallels to the Energy Crisis. The natural gas industry gained support in light of various national crises: skyrocketing oil prices in the mid 2000’s, war in the Middle East, severe economic recession. There exists fervor for foreign oil independence, and natural gas is almost entirely (98%) produced domestically.

The takeoff of drilling the Marcellus Shale in Pennsylvania is attributed to several factors including government support and the shale’s promise of creating high paying jobs, leasing royalties, and the tax dollars in a suppressed economy. In fact, Pennsylvania was able to close a $4 billion budget deficit with the help of state and local taxes paid by the Marcellus industry, on the order of $1.2 billion in 2011. These numbers are expected to climb to $1.4 billion in 2012 and continue to increase as the industry expands (Chesapeake Energy 2011).

The 2011 report entitled The Pennsylvania Marcellus Natural Gas Industry: Status, Economic Impacts, and Future Potential shows that Pennsylvania is currently self-sufficient in its supply of natural gas and is set to become a regional exporter. It also states that if production expands to a potential 17 BCF/day by 2020, the Marcellus could become the largest producing gas field in the United States (Considine et al. 2011), exceeding even Texas in gas production.

Each state has a distinctly different stake in the development of the Marcellus Shale. The states most involved in drilling are Pennsylvania, West Virginia, and Ohio. New York and Maryland are also involved, but are taking a cautious approach. New York Governor Paterson ordered a moratorium on natural gas drilling within the state borders in 2009. He directed the New York Department of Environmental Conservation (DEC) to complete a comprehensive study on the environmental effects of drilling the Marcellus Shale. One of the major concerns leading to his decision is that New York City has a special permit to not filter its drinking water supply. Wastewater discharge upstream of New York City could possibly revoke that permit, or require extensive amounts of money for a global upgrade of its system. Biding time may turn out to be a good decision, as they observe what happens as Pennsylvania charges headfirst into the industry. Environmental laws may become more stringent from ramifications in other states.

NY DEC's Draft Supplemental Generic Environmental Impact Statement (SGEIS) published in 2011 contains valuable information on the effects of the natural gas industry in Pennsylvania. New York makes the Draft SGEIS available to the public via its website, and are currently soliciting questions and comments from its citizens with regard to hydraulic fracturing. These questions must be submitted by December 12, 2011, and will be answered openly by the NY DEC. Arguably, it seems more information can be gathered on Pennsylvania from the NY DEC's Draft SGEIS than from a multitude of Pennsylvania's own government agencies.

1.5 Markets for Natural Gas

Strong markets exist for natural gas in the United States. 98% of domestic gas use is also produced within the United States. Natural gas currently fuels over 20% of electrical power in our nation, second only to coal. More than 85% of new electrical generation capacity in the last decade is for natural gas powered plants. The reason for this is that it is cost effective, on the order of about 40% less costly, and much more environmentally friendly than coal (EIA 2011).

The market for natural gas is expected to have a leading proportion of its supply from shale gas by 2035. It can be seen in Figure 1.5a that as of yearend 2009, tight gas plays were responsible for the largest supply of dry gas at 28%, with shale gas coming in at half that amount. In 2035, shale gas is anticipated to supply the highest proportion of dry gas in the United States at 45% of supply.

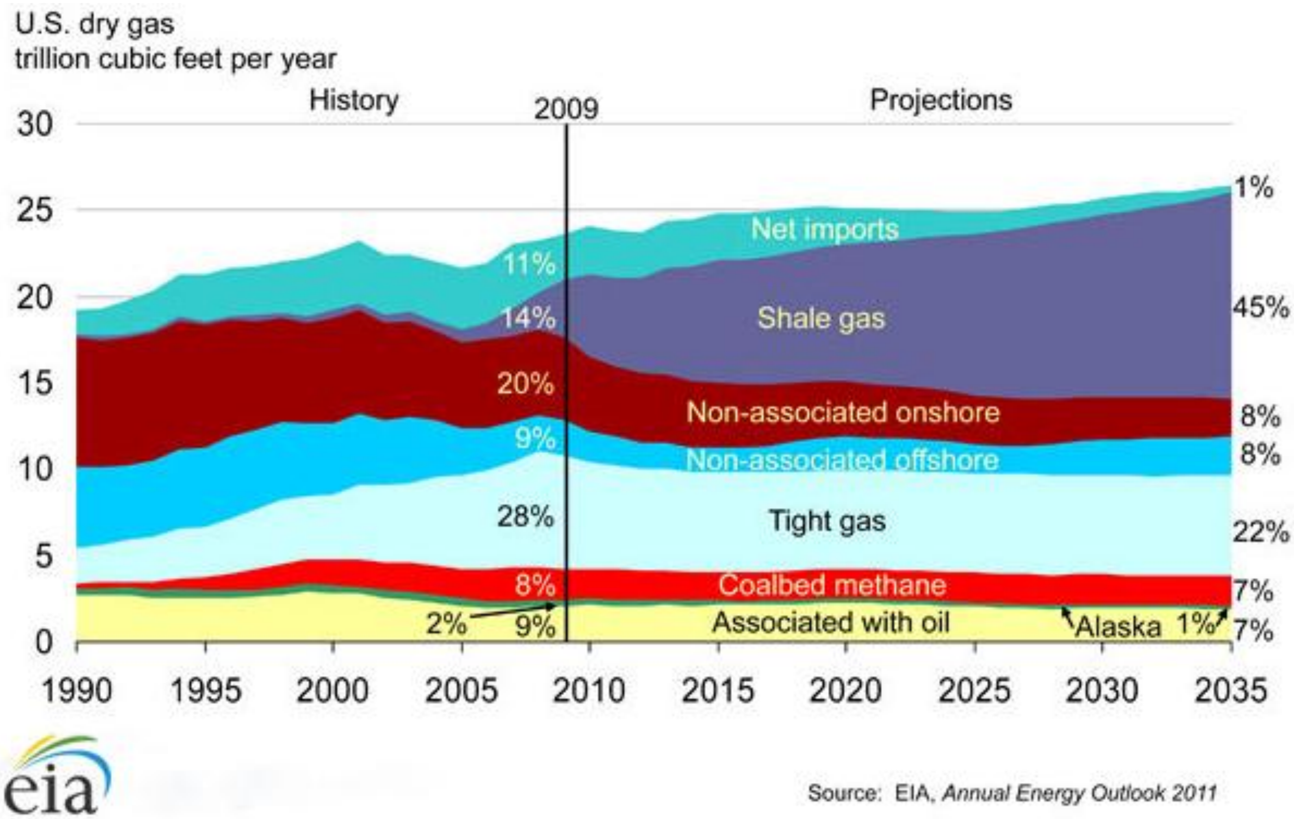


Figure 1.5a: Projections of Natural Gas Sources
Source: Energy Information Adminstration: Annual Energy Outlook, 2011.

The cost efficiency and lower emissions of natural gas are proven on a local scale. In January 2011, Penn State announced the conversion of its University Park West Campus steam power plant, located on Burrowes Street, from a long tradition of burning coal to using natural gas. Its East Campus power plant already runs on natural gas. In expectation of higher regulations on emissions and pollution from coal-fired power plants, they had two options: install scrubbers to reduce coal fired pollutants, or switch to another form of energy. Installation of scrubbers would have cost an estimated $35 million dollars. After weighing the cost benefit scenarios for various alternative fuels such as natural gas, biomass, and wind, Penn State decided to pursue a natural gas as a fuel source. This project will be in the range of $25-$35 million.

When asked if activity in the Marcellus Shale had affected his choice, Penn State Senior Vice President for Business and Finance Al Horvath said that he expects the regional drilling of the Marcellus Shale will fuel them with a steady supply. Horvath said using natural gas will decrease carbon emissions on campus by 37%, and the switch is expected to be completed by 2014 (Danahy 2011).

Natural gas as an alternative fossil fuel for power plants and vehicles is truly cleaner than traditional oil and coal sources. The following Figure 1.5b shows emission levels for the major fossil fuels.

Fossil Fuel Emission Levels
- Pounds per Billion Btu of Energy Input

Pollutant	Natural Gas	Oil	Coal
Carbon Dioxide	117,000	164,000	208,000
Carbon Monoxide	40	33	208
Nitrogen Oxides	92	448	457
Sulfur Dioxide	1	1,122	2,591
Particulates	7	84	2,744
Mercury	0.000	0.007	0.016

Figure 1.5b: Fossil Fuel Emission Levels between Natural Gas, Oil, and Coal
Source: EIA, Natural Gas Issues and Trends, 1998.

According to this data, a retrofitting or replacement from a coal fired power plant to a natural gas power plant would decrease carbon dioxide emissions by 43.75%, nitrogen oxide emissions by 80%, and nearly eliminate sulfur dioxide emissions. Nitrogen oxides and sulfur dioxide emissions are precursors to acid rain. No solid waste is created with natural gas, and no mercury is emitted.

Retrofits are much more costly and in some scenarios, building a new natural gas fired power plants beside an existing coal powered plant would be more cost effective and allow a nearly seamless transition. Factors such as a lack of space would lead to a retrofit, as in Penn State’s situation on the corner of Burrowes Street and College Avenue.

Another tie that Centre County has to natural gas can be seen in its transportation authority. The Centre Area Transportation Authority’s (CATA) entire fleet of buses run solely on compressed natural gas, as well as many other fleet vehicles in the United States. Natural gas produces only 71% of the carbon dioxide emissions as oil, little particulate matter, virtually no sulfur dioxides and far less nitrogen oxides than both oil and coal. Infrastructure currently does not allow CNG to be economical for passenger cars. Fleet vehicles, however, greatly benefit from the use of CNG as a vehicular fuel.

In Figure 1.5c, the Department of Energy shows the fuel prices of compressed natural gas (CNG) compared to diesel, which is appropriate due to the heavy type of vehicles which use diesel. These vehicles are typically mass-transit or fleet vehicles, in which infrastructure required for conversion to CNG may pay dividends. CNG per diesel gallon equivalent (adjusted for its energy generating capacity) remained at a relatively constant price of around $2.75 through the spike in the summer of 2008 where diesel reached nearly $5.00 a gallon. This illustrates the potential price advantages of nationally produced fuelds over foreign oil.

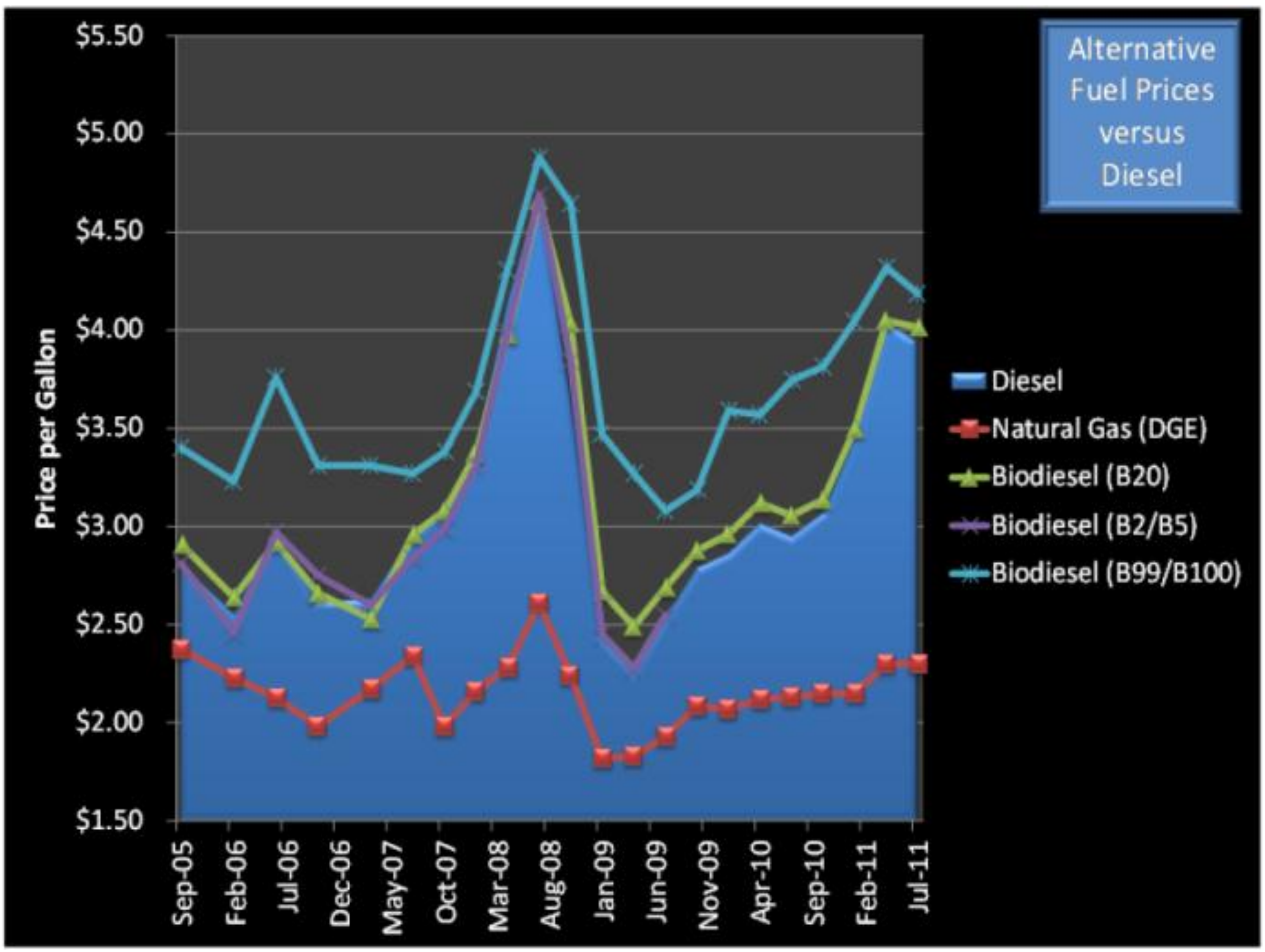


Figure 1.5c: Price Per Gallon of Diesel vs. Alternative Fuels, 2005 through 2011
Source: Department of Energy, 2011.

1.6 Revival of Industry

Activity in the Marcellus Shale may reinvigorate cities within the Rust Belt which have long been devoid of industrial capacity. This happens in two ways: by increasing demand for manufactured products to support drilling activity, and by offering a reliable supply of fuel for those companies to use.
The Vice President of U.S. Steel Tubular, Douglas Matthews, is excited about the Marcellus Shale. U.S. Steel is based out of Pittsburgh and currently uses coal for its manufacturing process. Matthews said that "the steel industry could convert tomorrow" to natural gas (Pittsburgh Quarterly 2010). He alludes to higher regulations on carbon emissions forcing the balance in favor of natural gas. Matthews would be taking a course of action similar to Penn State's conversion. No longer is lack of a steady fuel supply a concern for the tubular steel industry in Pennsylvania.

Not only would natural gas help U.S. Steel power its plant with fewer emissions and at a lower total cost, drilling for natural gas increases its consumer base. U.S. Steel doled out $6 million to build a new fabrication shop in Washington, PA to service the volume of tubular steel required as well casing for the Marcellus industry.

Another steel revival sparked by the Marcellus in a Rust Belt city is occurring across the Pennsylvania border in Youngstown, Ohio. The French Company Vallourec is building a $650 million, 1 million square feet steel mill in Youngstown. The President of the American based company, V&M Star, Joel Mastervich, said that Youngstown was chosen for its existing industrial infrastructure, experienced workforce, proximity to customers in the Marcellus Shale, and steady supply of natural gas (Brady 2011).

The industrial implications of the Marcellus are widespread, and are also influencing the chemical industry. Natural gas liquids (NGL's) are an important derivative of the natural gas industry. NGL's include hydrocarbons such as butane and propane which are byproducts of refining natural gas. Currently there are no markets for these NGL's in Appalachia, but Shell Oil & Gas plans to create a market by using some of the NGL's as a feedstock for an ethane cracker.

An ethane cracker converts ethane into ethylene, which serves as the basis for plastic products such as polyethylene. Polyethylene can be manufactured into commercial products such as paints, dyes, coatings, and plastics. Ohio, West Virginia, and Pennsylvania are vying for the ethane cracker right now, as it will creates thousands of jobs and tax revenue. West Virginia is lobbying vigorously for Shell's cracker. It could regain 12,000 chemical jobs, along with $7 billion in chemistry output. 140,000 chemical jobs were lost from 1995 to 2005 alone; these numbers exclude losses during the economic downturn which surely eliminated a large portion of what remained (Hohmann 2011). These are just a few instances of how the Marcellus Shale is helping revive industry in Appalachia.

Chapter 2
Technology

For the Marcellus Shale to become an economically attractive source of natural gas, two major technological advancements were required: horizontal drilling and hydraulic fracturing. Horizontal drilling allows a larger area to be drilled from a single pad and hydraulic fracturing cracks apart the impermeable shale to release the gas trapped inside.

2.1 Horizontal Drilling

Horizontal drilling is an evolution of traditional vertical drilling. In vertical drilling, a well is drilled straight down until it reaches the target formation. The characteristics of the rock formation, such as its permeability, determine the success of this type of well. Formations with high permeability produce gas due to pressure differentials. Shales are characterized by their low permeability, thus they need mechanical assistance to produce gas. Exploitation of shale formations such as the Barnett, Fayetteville, Haynesville, and Marcellus Shales would not be possible without the use of horizontal drilling.

Horizontal drilling begins as a vertical well, turns, and drills horizontally into a formation. Shale formations have many vertical fractures, and the use of horizontal drilling intersects more of these natural fractures perpendicularly, opening more venues for gas to escape in preparation for fracturing. Drilling takes an average of 30 days to complete. After the drill rig leaves, a hydraulic fracturing crew comes in with specialized equipment to stimulate the well to open more pores for gas to collect.

The first horizontal well was drilled near Texon, Texas in 1929. The second horizontal well was drilled in 1944 in the Franklin Heavy Oil Field in Venango County, Pennsylvania. Significant research was performed on horizontal drilling in China, Soviet Russia, France, and Alaska in the 20th century. In recent years, U.S. developers fine-tuned the technology of drilling shales such as the Bakken Shale in North Dakota and brought it to PA to use in the Marcellus Shale.

Horizontal drilling brings a host of benefits. A single well pad holds an average of 6 to 8 horizontal wells. Each well can drill up to 1.5 miles in length horizontally, to reach resources beneath environmentally protected areas, such as wetlands, urban communities, historic buildings, shallow lakes, railroads, and the sea. Figure 2.1a illustrates the difference between a horizontal and vertical well.

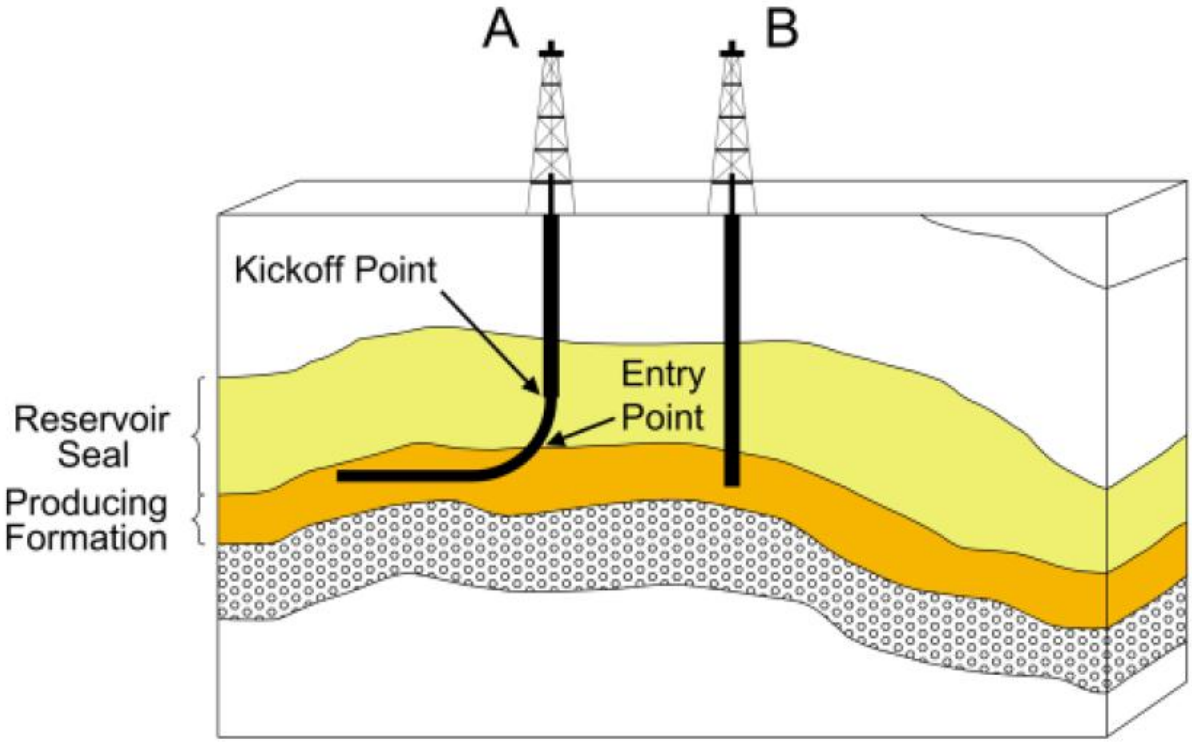


Figure 2.1a Horizontal Drilling (A) Versus Traditional Vertical Drilling (B)
Source: Horizontal Drilling by Lynn Helms, 2011.

The New York DEC proved in the Draft SGEIS that horizontal wells are more beneficial than vertical wells. For example, in order to develop 640 acres of land with vertical wells, up to 80 acres of disturbance would be necessary. The same 640 acres could be drilled with a single well pad containing 8 horizontal wells, with about 8 acres of total disturbance (2011). That is 10% of the disturbance of a traditional vertical method.

For a real world example of the potential of one well pad with multiple horizontal wells, consider this: a well pad is hypothetically positioned on the intersection of Park Avenue and Atherton Street in State College, PA. Recall that a horizontal well can reach approximately 1.5 miles in any direction. Employing horizontal drilling, the drill rig could reach North Atherton WalMart. That is a straight distance of 1.6 miles, or 8,500 feet. For four additional wells drilled on the same pad, you could also reach beneath Beaver Stadium, Fuji & Jade Garden, Park Forest Village, and University Terrace Apartments on University Drive.

While it may seem silly to consider a well pad in the middle of Park Avenue and Atherton Street, this situation is manifested in reality at the University of Texas. A single well pad is located on the University of Texas's Arlington campus. This well pad is host to over 22 horizontal wells. The reduction in footprint thanks to horizontal drilling is favorable on protected campus land. They are expecting to withdraw a cumulative 110 BCF of natural gas from this one well pad alone.

University of Texas's President Spaniolo wrote various letters to the community throughout the life of the wells. His first announcement letter came on October 25, 2007 explaining that Carrizo Oil & Gas had completed seismic studies and were going to install natural gas wells on the southeast corner of their campus. In his letter from March 12, 2010, he is quoted saying that the six wells that went into production in 2008 have generated $5.5 million in royalty revenue to the University.

Compared to a vertical well, a horizontal well increases production capacity, and thus profitability, by over 3.2 times (Horizontaldriling.org 2010). One drawback is that a horizontal well has higher capital costs, on the range of 2 to 3 times the price per foot of a comparable vertical well. However, the smaller well pad footprint and higher production, plus the ability to tap into resources that are infeasible with vertical drilling, makes horizontal wells a worthwhile investment.

A visual reference to a typical Marcellus horizontal well is provided in Figure 2.1b on the following page. Horizontal wells begin vertically. The borehole is drilled to a depth just beneath the lowest freshwater aquifer. At that depth, the drill bit is removed so that a tubular steel casing can be installed, and cement is pumped between the casing and the borehole to restrict migration of fluids into drinking water. The drill is reinserted and deepens the well. Additional rings of casing and cement may be installed around the borehole before the last phase of casing, called the production casing. Individual states regulate casing and cementing requirements.

A horizontal well starts to turn at the kickoff point. The kickoff point is reached a few hundred feet above the target formation. At this point, the drill bit is retracted so that a directional motor can be installed between the drill bit and pipe. This step also clears the hole of cuttings and drilling mud.

The operator, equipped with 3D imaging software, drills on a radius until he hits the entry point of the formation. The radius ranges from 300 to 500 feet. Once in the formation, to maximize the pay zone, the operator steers very carefully to keep the borehole within the confines of the formation. This borehole will be cased and cemented one final time before completion in preparation for the frack crew to come in.

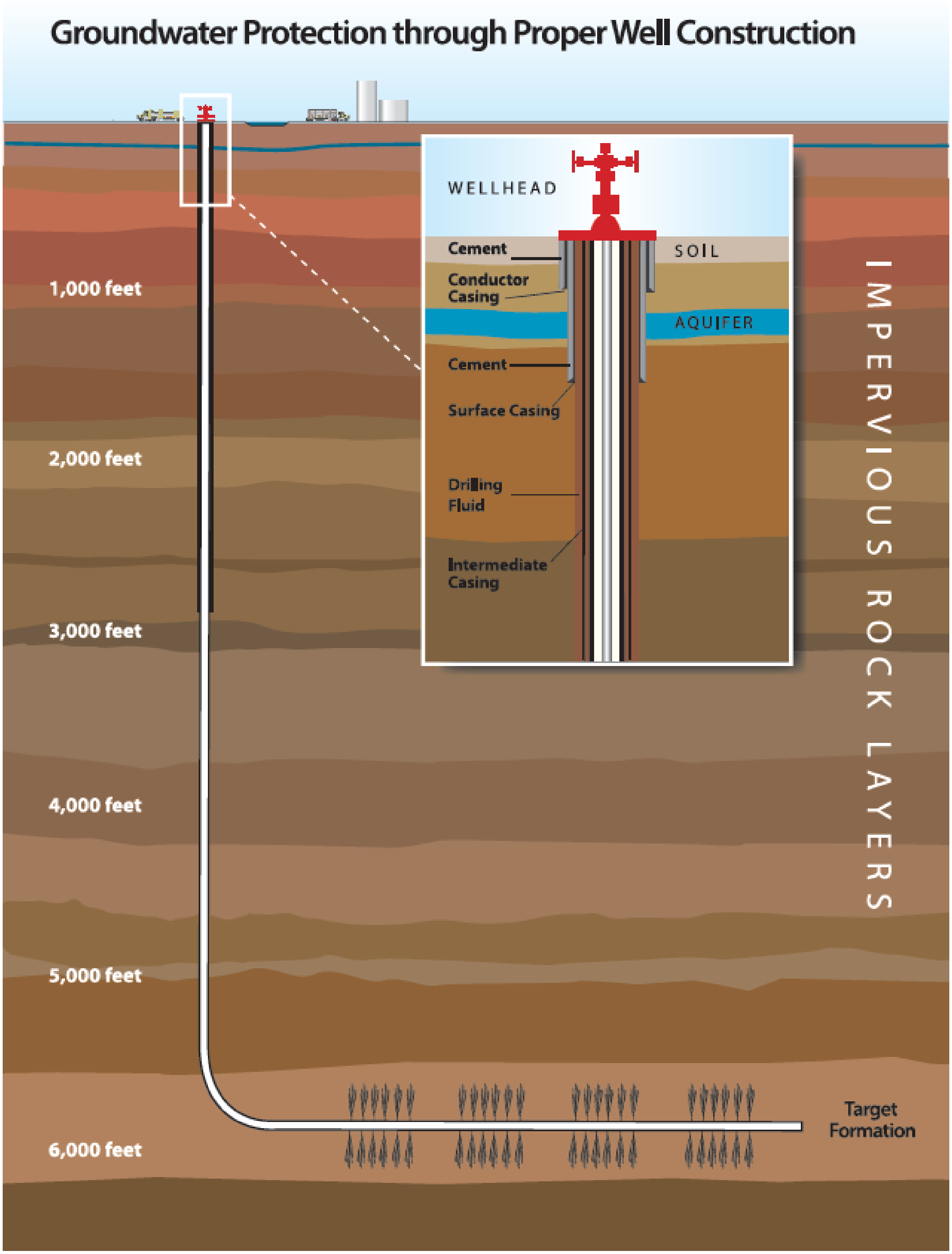


Figure 2.1b: Expanded View of a Horizontal Well
Source: American Petroleum Institute, 2011.

2.2 Hydraulic Fracturing

The second component to retrieving the gas within the shale is hydraulic fracturing. Hydraulic fracturing was pioneered by Halliburton. They developed this technology to use in the Hugoton Field in Kansas in 1947. Hydraulic fracturing is at the heart of the controversy because of its usage and potential impacts on water supplies; hydrofracturing requires approximately 5 million gallons of fresh water withdrawal to fracture one well, and 10-30% of that returns to the surface as toxic flowback when the frack job is complete (Chesapeake Energy 2011). According to that information, between 500,000 gallons and 1.5 million gallons of fracturing fluid returns to the surface.

A fracture job is performed after the horizontal well has been drilled into the target formation; at this point, the drill rig leaves. A fracturing crew comes in now to complete the job, which takes less about a week.

The initial step in hydraulic fracturing is to perforate the production casing that was cemented in place by the horizontal drilling crew. A fracturing job consists of "stages," each of which are approximately 1,000 feet in length. A horizontal well can have about 6 frack stages. For each stage, the following process is repeated: a perforating gun is inserted on an electrically charged string into the well to the end of the bore. An electrical charge is sent down the string and the perforating gun puts off a shot, increasing fractures in three dimensions in the shale. The perforating gun is retracted. The horizontal portion of the well illustrated in Figure 2.1b shows perforations from the perforating gun in about 4 frack stages.

The second step is to inject a large volume of hydraulic fracturing fluid at thousands of pounds of pressure into the wellbore. This fluid contains water, chemical additives, and sand which serve to propagate the cracks opened by the perforating gun. The sand rushes into these newly opened pores and acts as a propant to keep the fractures open. The fracturing fluid is then flushed out, while the sand remains, holding open pathways for the gas to escape. Each frack stage is plugged intermediately to allow gas to accumulate. A temporary wellhead is installed.

After perfing, fracking, and plugging a few more stages, the fracturing crew leaves the well site. The plugs are removed and a permanent wellhead is installed. The average Marcellus well can produce gas for 40 to 50 years.

According to Chesapeake Energy's September 2011 fact sheet, hydraulic fracturing fluid is approximately 98% water and sand, with the remaining 2% as additives. Figure 2.2 shows the proportions of water and sand injected into the well.

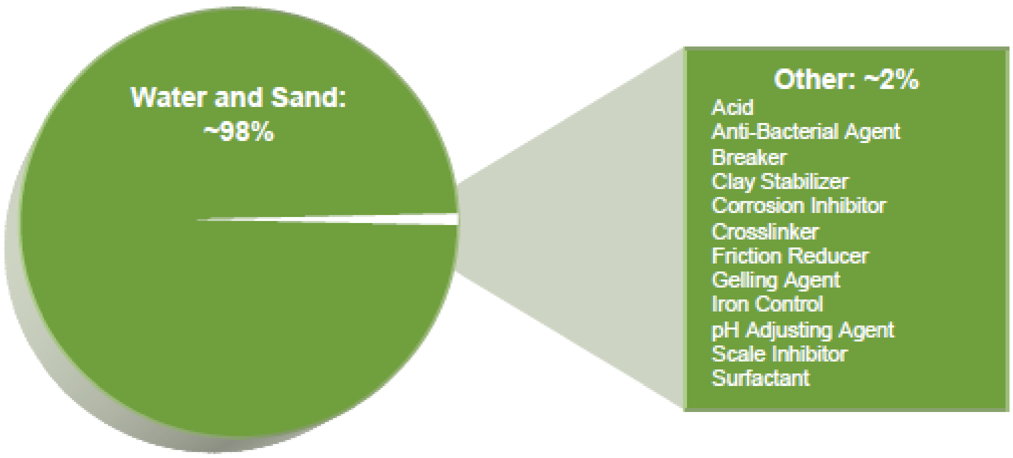


Figure 2.2: Hydraulic Fracturing Fluid Fractions
Source: Chesapeake Energy, 2011.

Fracfocus.org outlines the different steps of chemicals used in hydraulically fracturing a Marcellus Shale well in Pennsylvania (2011). Additives for each stage are detailed below and will be addressed in Chapter 3 in the Contaminants of Concern section:

Table 2.2: Uses of Hydraulic Fracturing Chemicals
Source: Fracfocus.org, 2011.

Biocides:	prevent the growth of bacteria that may interfere with the operation (bromine-based solutions or glutaraldehyde)
Scale inhibitor:	control the precipitation of carbonate/sulfate minerals (ethylene glycol)
Iron Control & Stabilizing Agents:	control precipitation of iron compounds to keep them in a soluble form, (citric acid or hydrochloric acid)
Friction reducers:	Decrease friction in the tube by up to 60%, this is what makes it a "slick water" frack. **(**Potassium chloride or polyacrylamide-based compounds
Corrosion Inhibitors:	to prevent steel from degrading **(**N,n-dimethyl formamide, ammonium bisulfate)
Gelling agents:	thickens water based solution to transport the sand (guar gum
Cross-linkers:	these make the gelling agent more able to pick up the sand and transport it to the fractures. **(**Boric acid or ethylene glycol)
Breaker solution:	added after the propant has been delivered, added to counteract the gelling action of the cross-linking agents so they can get the fluids out of the well while leaving the sand in.

2.3 Water Usage

The average volume of water needed to mix with the above chemicals for fracturing is 5 million gallons per horizontal well bore of about 4,000 feet (New York Department of Environmental Conservation, 2011). The exact amount ranges from 2.7 million gallons to 7.8 million gallons. Most of this water is fresh water. Fresh water can be withdrawn from nearby streams and reservoirs with appropriate permits, trucked by tankers, transmitted via piping, held nearby in an engineered impoundment, or placed in a centralized location to service multiple well pads.

In order to get a visual of 5 million gallons of water, an Olympic sized swimming pool is slightly more than half a million gallons of water, at about 660,000 gallons. To fracture one well, that's about 7.5 Olympic swimming pools' worth of fresh water.

According to the DEP's Bureau of Oil and Gas Management, there were 1,386 Marcellus wells drilled in Pennsylvania in 2010. Given an average of 5 million gallons per well, that would be 6,930,000,000 gallons. Water withdrawals are expected to increase as the number of gas wells drilled grows exponentially over the next decade. Chapter 6 of New York DEC's Draft SGEIS concluded that without regulation of the volume, timing, and rate of water withdrawals, the impact of thousands of withdrawals could severely impact water supplies and drinking water quality if treatment is dilution-based. The aquatic ecosystem, wetlands, and riparian resources could also suffer (2011). More in-depth discussion is presented in Chapter 3.

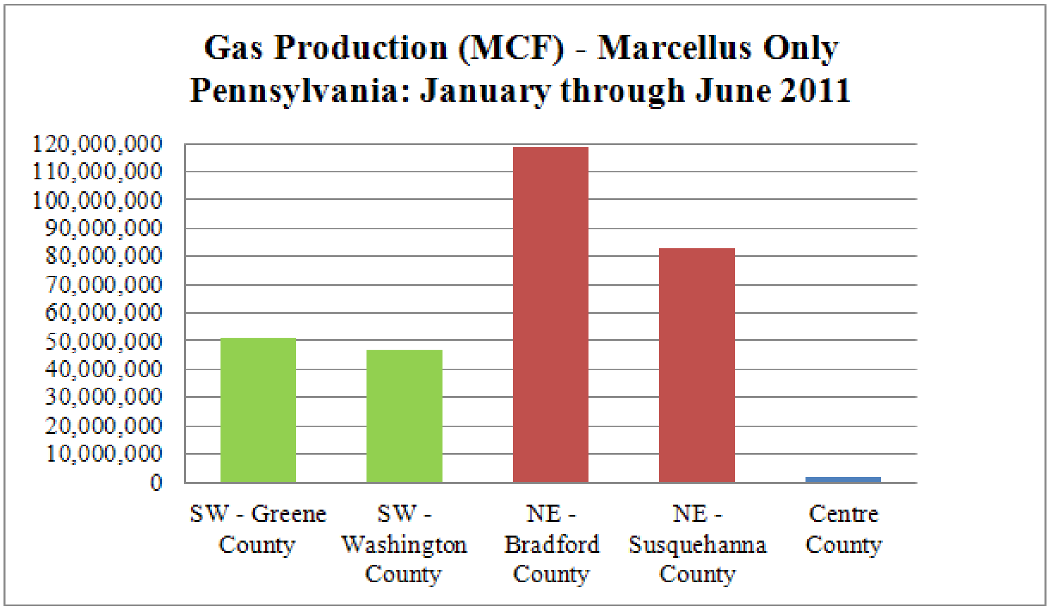
Chapter 3
Environmental Impact

While natural gas is proven to be a less environmentally damaging source of energy than traditional fossil fuels, the environmental burden occurs in its extraction. The embodied impact of drilling for natural gas causes some immediate concerns, including but not limited to: air pollution, noise pollution, bridge and roadway degradation, deforestation and segmentation of habitat, increased storm water runoff, and decreased property values. The overlying concern affecting all people in the Appalachian Basin and watersheds surrounding it is water quality related to the handling of fracturing fluids. These fluids are being produced in such high volumes due to Marcellus Shale activities, and legislation may not be enough to keep up and protect citizens in and near drilling states.

3.1 Options for Disposal

Fracturing fluid inevitably reaches the end of its useful life. While most of the fracturing fluid remains in the ground, hundreds of thousands of gallons return for disposal. The methods of disposal include treatment at a wastewater treatment plant, beneficial reuse, or deep injection well. Some solid byproducts may be trucked to a landfill. Theoretically, all of these methods have environmental advantages and drawbacks.

Data available from The Pennsylvania Department of Environmental Protection can assist in classifying which methods are used most frequently and which methods are most effective in eliminating or moderating water quality impacts. The PA DEP publishes data reports on gas production and waste disposal in six month periods. The most recent data (January to June 2011) was interpolated to examine three key areas of the state: the well-established Southwestern and Northeastern counties, and the experimental center of the state. Respectively, the counties representing each of these three regions are Greene County, Bradford County, and Centre County. Greene and Bradford Counties are the largest gas producers of their regions, while Centre is examined to provide scope. Compiled data can be seen in Figure 3.1a. For reference, a Pennsylvania County map is provided in Figure 3.1b, showing the locations of each of these counties.



COUNTY	GAS QTY (MCF)
SW - Greene County	51,063,821.71
SW - Washington County	46,900,664.00
NE - Bradford County	118,644,697.00
NE - Susquehanna County	82,924,945.17
Centre County	2,040,043.00

Figure 3.1a: Gas Production of SW, NE, Centre Counties: January - June 2011

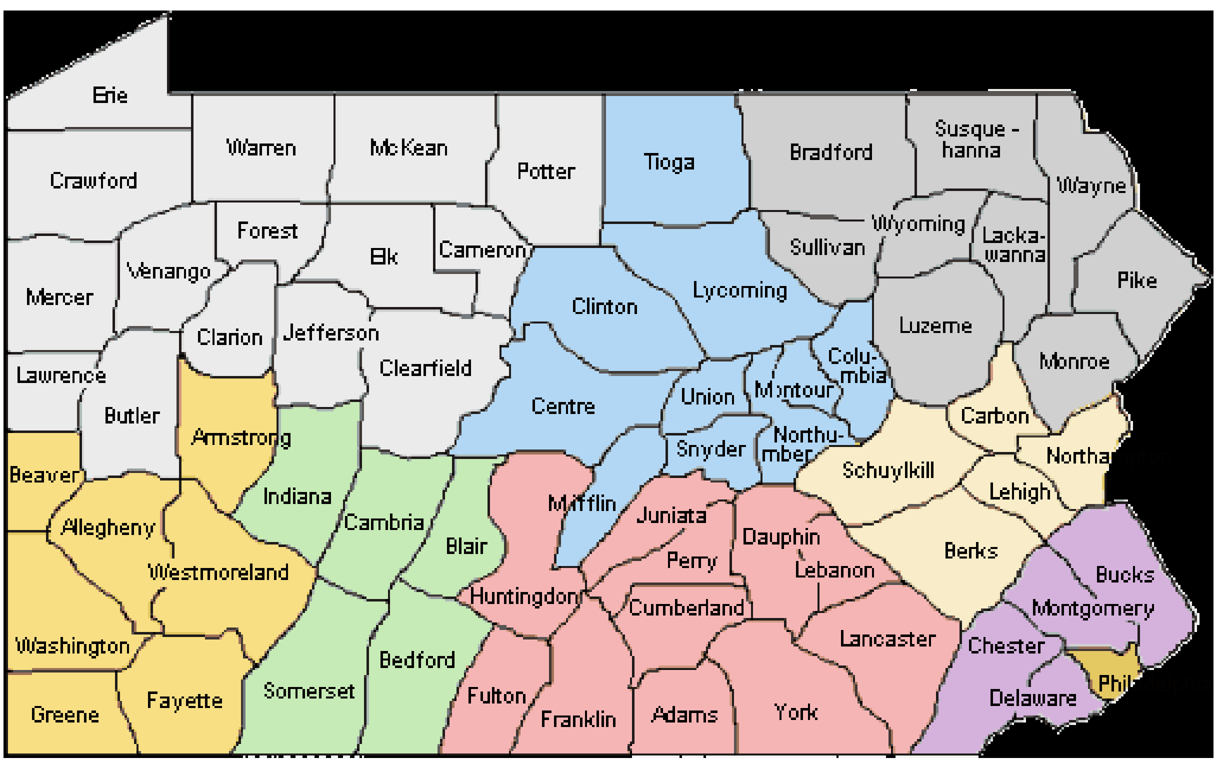
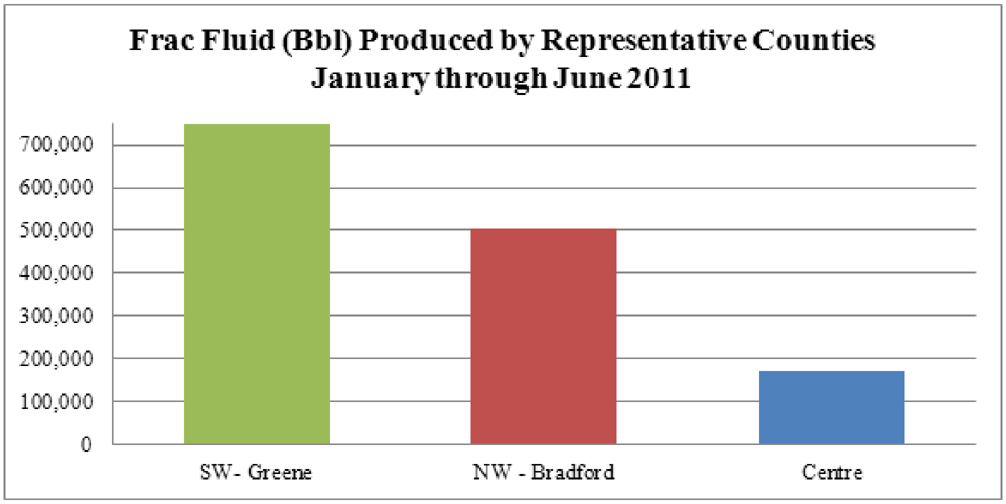


Figure 3.1b: Pennsylvania County Map
Source: Haponline.org, 2011.

Figure 3.1c shows the volumes of hydraulic fracturing fluid waste produced by each of the representative counties.



COUNTY	FRAC FLUID (BBL)
SW- Greene	748,797.10
NW - Bradford	501,900.80
Centre	171,275.00

Figure 3.1c: Frac Fluid Produced by Representative Counties: January – June 2011

Greene County, representative of Southwestern PA, produced the highest amount of fracturing fluid in the period from January to June 2011 at nearly 750,000 barrels. Bradford followed at over 500,000 barrels of frac fluid, and Centre at over 170,000 barrels. These numbers reflect the amount of frac fluid waste that comes from each portion of the state. It can be seen that even though Bradford County has the highest gas production rate, it generates a lower amount of frac fluid waste than Greene County. Perhaps this is due to the fact that Greene County requires more stimulation to produce gas than the organic rich, thicker shales of Northeastern PA as was seen in Figure 1.1c.

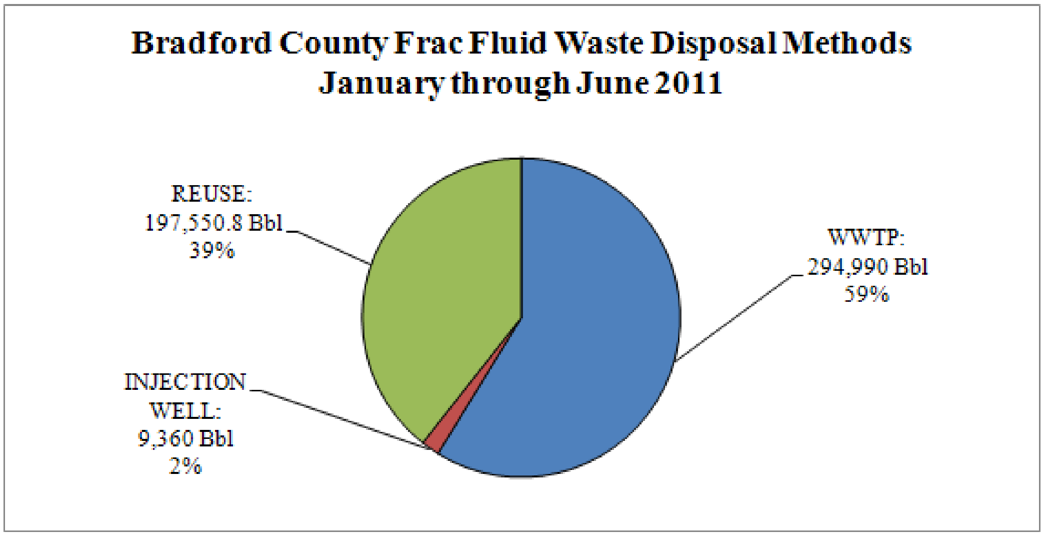


Figure 3.1d: Bradford County Frac Fluid Waste Disposal Methods

In the Northeast corner of Pennsylvania, Bradford County disposed of its fracturing fluid waste via three methods: waste water treatment plant (59%), reuse (39%), or an injection well (2%).

The wastewater treatment plant responsible for handling most of Bradford County's waste is Terraqua Resource Management located in Williamsport, PA. Ambiguity can be found in this data regarding what the final destination of processed frac fluids. Terraqua does not dispose the treated wastewater to a stream; rather they clarify it and return the fluid to the gas company to be reused in more drilling and fracturing processes. Should this then be characterized as reuse? This points out a flaw in the tracking system of fracturing fluids. A small amount of brine waste, approximately 115 barrels, was trucked outside of Pennsylvania to the industrial water treatment plant Clean Harbors of Baltimore, Inc.

39% of Bradford County's fracturing fluid was reused. It was trucked elsewhere (in and outside of Bradford County) for use in drilling or plugging other wells. The destination of these fluids is determined by the operating company in an effort to reduce freshwater withdrawals and decrease treatment costs.

All of the injection well-bound fluid from Bradford County goes to Paris, Ohio, which is 332 miles, or an approximately 6 hour drive from Bradford County. 9,360 barrels of fracturing fluid were trucked this distance.

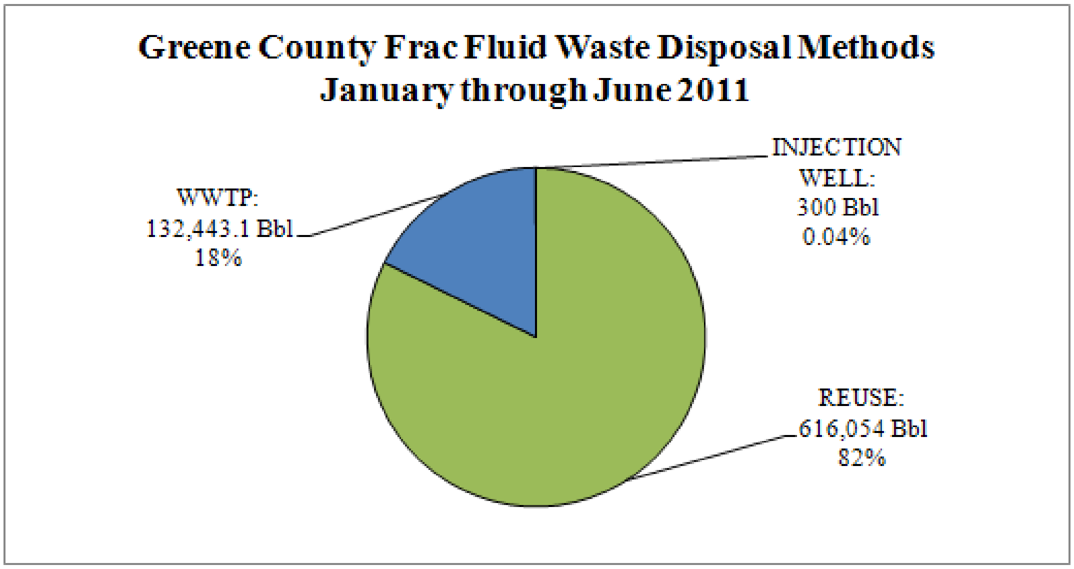


Figure 3.1e: Greene County Frac Fluid Waste Disposal Methods

In the Southwest portion of Pennsylvania near Pittsburgh, Greene County disposed of most (82%) of its fracturing fluid by reuse. The WWTP's accepting frac fluid waste from Greene County are located in Ohio and Pennsylvania. Of the fluid sent to WWTP's from Greene County, Pennsylvania plants treated 125,796 barrels (95%) of the fracturing fluid, while Ohio treated 6,647 barrels (5%) of it. The injection well accepting Greene County's brine is located in Reno, Ohio, which is approximately 95 miles or a 2.5 hour drive. Only 300 barrels of frac fluid were sent there.

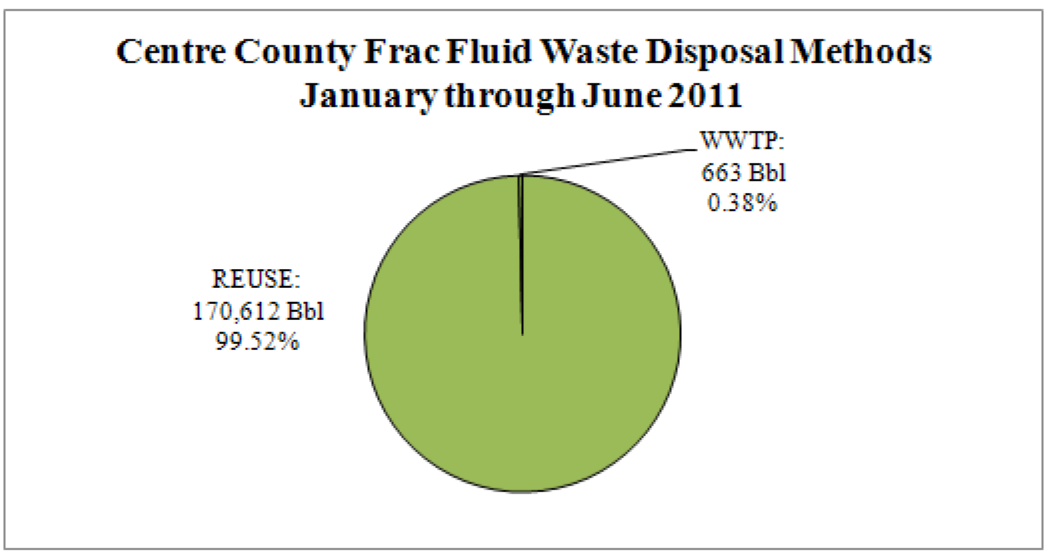


Figure 3.1f: Centre County Frac Fluid Waste Disposal Methods

Centre County's fracturing fluid waste was reused mostly in drilling new wells or plugging old wells. Only 663 barrels of frac waste was sent to WWTP's for disposal. This can be attributed to its proximity to new experimental wells which need water.

In summary, the data utilized in creating the preceding charts show that in Northeastern Pennsylvania, Bradford County's most popular method of disposal is treatment at an industrial water treatment plant in Williamsport. In Southwestern Pennsylvania, Greene County reuses a majority of the fluids for drilling and plugging other wells. Greene and Bradford County had small amounts of frac discharge to deep injection wells located in Reno and Paris, Ohio, respectively. Centre County's main method of disposal of fracturing fluid is almost entirely reuse. Figure 3.1g shows Pennsylvania's preferences as a whole from January to June 2011.

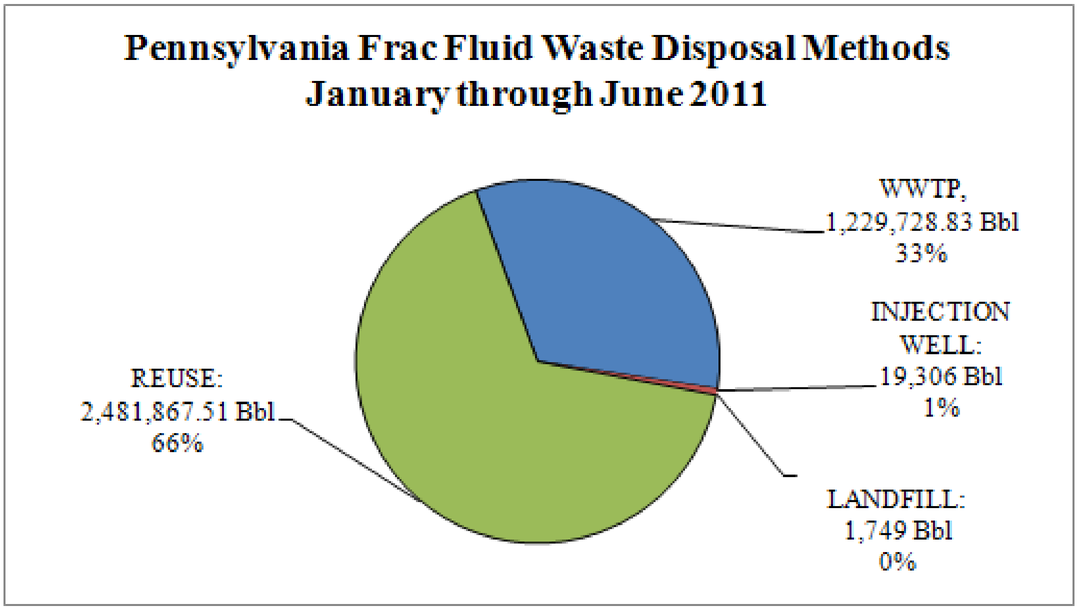


Figure 3.1g: Total Pennsylvania Frac Fluid Waste Disposal Methods

A final summary of the data for Pennsylvania overall shows a situation where frac fluid reuse is most popular at 66%, with treatment at water treatment plants coming in second at 33%. This is slightly misleading because all reuse will eventually have to be discarded. With each trip down the well, less comes back up, but reuse is just the prolonging of disposal, not an actual method of disposal.

3.2 Reuse

Greene County shows why reuse is an effective way to create a situation where all parties involved, environmentalists and industry alike, can be satisfied. Reuse can reduce the costs of disposal, environmental impact, and water withdrawals. Frac fluid may be blended with freshwater in an impoundment, combined with fresh chemicals and injected to fracture another well. It may also be used as water for horizontal drilling, or to plug an expired well. With each trip down the well, less of the initial flowback returns to the surface. However, this advantage may be offset by the accumulating concentration of chemicals, salinity, heavy metals, and radioactivity with each trip down a well.

Reuse is currently popular and should be expected to grow as a disposal method in counties where new wells are being prospected and demand for fluid is high, such as Centre, Clinton, Clearfield, and Clarion. In time, when well production slows, reuse will become less advantageous and most will likely end up at wastewater treatment plants. Reuse may offset the amount of freshwater withdrawn, though some fluid inevitably must be treated or injected.

3.3 Deep Well Injection

Deep well injection is the least popular method of disposal in the selected Pennsylvania counties. Bradford and Greene Counties trucked less than a combined 3% of their fracturing fluids to deep well injection sites in the first half of 2011. However, deep well injection could alleviate the slow-growing, accumulating toxin scenario found in waste water treatment that will be discussed in Section 3.4.

In Bradford and Greene Counties, every barrel of frac fluid set for deep well injection was trucked to Ohio, as much as 6 hours away. Pennsylvania is not a prime candidate for deep well injection due to its geology. However, there are 7 deep injection wells operating in Pennsylvania as of November 2011. It can be seen below in Figure 3.3, generated by NPR, where these wells are located. This number may soon change. As reported by State Review of Oil and Natural Gas Environmental Regulations (STRONGER), there are pending applications for over 20 disposal wells in Pennsylvania (2011).

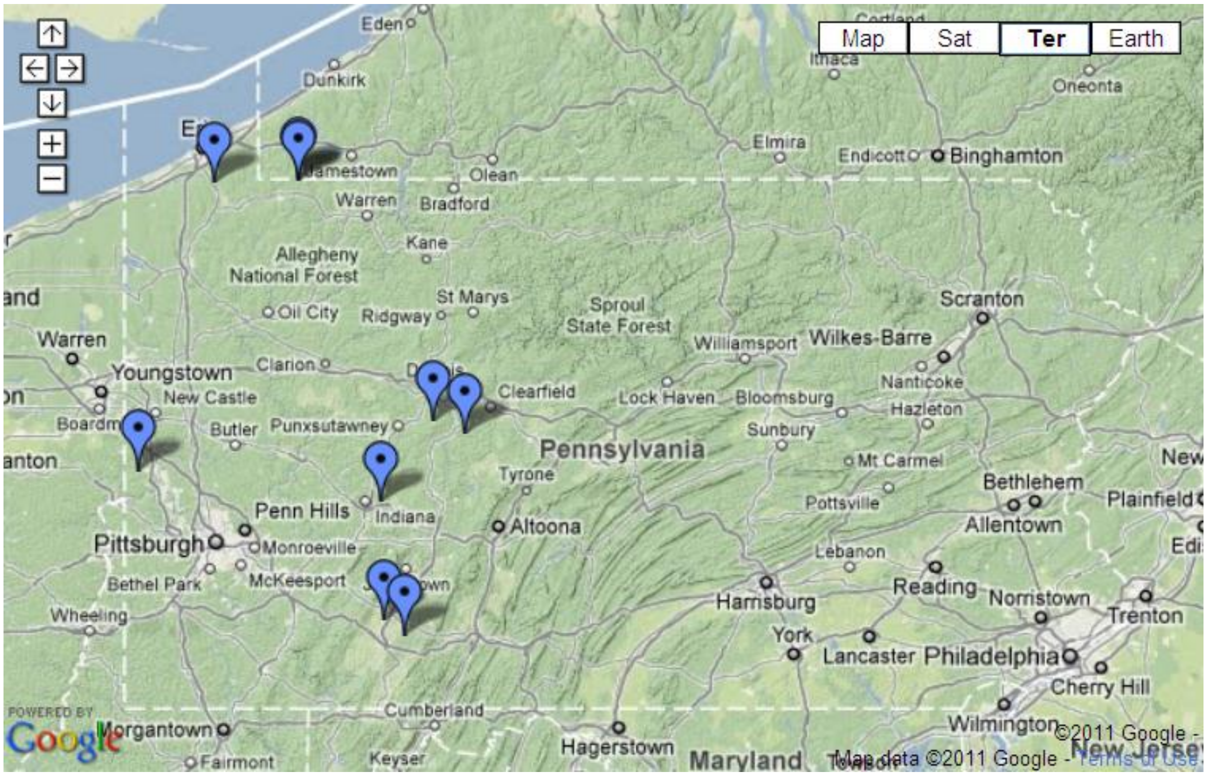


Figure 3.3: Locations of Pennsylvania Deep Injection Wells
Source: NPR.org, 2011.

The fluid is injected at high pressures into a designated, monitored well site into a tight rock formation where petro geologists believe migration is unlikely. Regulation of injection wells is performed by the Underground Injection Control (IUC) program.

Five of these PA wells inject brine into the Huntersville/Oriskany Sandstone formation beneath the Marcellus, while others inject into the Gatesburg and Medina formations. The majority of these wells have a monthly injection allowance of about 30,000 barrels. EXCO Resources owns the two wells in Clearfield County with a much lower injection allowance of about 4,200 barrels a month. Only one of the seven wells is commercial; the majority are private.

There is small potential to trigger inconsequential earthquakes from local deep well injection. The additional pressure and volume of fluid increases the force on the opposing strata and reduces friction, which may induce seismicity.

Other issues associated with deep injection wells are old, poorly maintained wells leaching chemicals into water wells, noise and local air pollution from heavy tanker traffic transporting to and from the site every day, rutting and destruction of rural roads under designed for carrying such loads, and decreased property values of nearby households. It is very unlikely that deep well injection becomes a staple of fluid disposal in Pennsylvania due to its geology and relative expense when compared to Ohio. Pennsylvania used deep well injection for less than 1% of its fluid disposals in 2011.

3.4 Treat and Release

The remaining method of disposal to be discussed is treatment. It appears that the eventual option for Marcellus Shale frac flowback is to be trucked to a treatment plant.

Some industrial waste water treatment plants are in pre-construction stages, and some are currently operating. But for a period of time when the system was flooded with large volumes of water, standard municipal sewage treatment plants were accepting flowback. Some still are today – there were 6,784 barrels designated as going to a standard municipal sewage treatment plant in the first half of 2011. For the state as a whole, this number is non-threatening, but to residents downstream of these plants there is a concern that they are not sufficiently equipped to remove all hazardous materials from the fluid.

There are no restrictions on the proximity of these effluent discharge points to drinking water supplies. Effluent could contain high levels of Total Dissolved Solids (salinity), heavy metals, radiation, and residual chemicals.

As reported in the Draft SGEIS by NY DEC (p. 17, 2011):

> "The disposal of flowback water could cause a significant adverse impact if the wastewater was not properly treated prior to disposal. Residual fracturing chemicals and naturally-occurring constituents from the rock formation could be present in flowback water and could result in treatment, sludge disposal, and receiving-water impacts. Salts and dissolved solids may not be sufficiently treated by municipal biological treatment and/or other treatment technologies which are not designed to remove pollutants of this nature."

The overarching issue is that of the water that is legally dispersed into streams from treatment plants that are adhering to ill-enforced or under-defined standards.

Important, life-sustaining rivers in Pennsylvania are flooded with this discharge, including the Monongahela River, the Susquehanna River, and the Delaware River. The Monongahela River in the Pittsburgh area provides fresh water for more than 800,000 people; the Susquehanna River in the Harrisburg-Baltimore area provides drinking water for six million people; and the Delaware River around Philadelphia sustains 15 million people.

American Rivers reports that the #1 most endangered river in the United States is the Upper Delaware River (2011). 19 million gallons of wastewater per day are predicted to be released in Pennsylvania in 2011. Chesapeake Appalachia and Statoil stated they will drill 13,500 to 17,000 gas wells in the region over the next two decades. Energy companies are asking for permits to withdraw fresh water from the Upper Delaware River, and there are talks regarding treatment facilities on the river. The concerns that American Rivers have regarding the withdrawals and flows are legitimate.

Before the moratorium, New York was home to a treatment plant that discharged flowback water into Southern Cayuga Lake near Ithaca, New York. Another discharged to Owasco Outlet near Auburn, New York. A West Virginia plant in Wheeling discharged untreated water into the Ohio River.

The issues associated with the various chemicals encompass a kaleidoscope of illnesses. When brine laden with carcinogenic chemicals and radioactivity enters a stream, it can cause a fish kill, neurological problems for the inhabitants, increased risk of bone, lung, and other types of cancer, and endocrine disruptions.

3.5 Contaminants of Concern

Two categories of contaminants need to be considered. The first is fracturing chemicals, and the second is naturally occurring radioactive materials (NORMs). Fracturing fluids sent down the well bore contain manmade chemicals, and come back up with heavy metals, NORMs, and high levels of Total Dissolved Solids from within the Earth’s crust. More information on NORMs can be found in Section 3.6.

The Endocrine Disruption Exchange (TEDX) studies chemicals used in hydraulic fracturing. Recall that an average deep shale horizontal well for Chesapeake Energy takes about 5 million gallons of fresh water to fracture. If the reported 10% to 30% of the fracturing fluid resurfaces, and the reported 1% of the mixture injected per well is comprised of chemicals, that is 5,000 to 15,000 gallons of pure chemicals resurfacing from a single well.

Flowback contains chemicals used as acids, biocides, breakers, clay stabilizers, corrosion inhibitors, crosslinkers, defoamers, foamers, friction reducers, gellants, pH control agents, propants such as sand, mineral scale controllers, and surface-tension reducing surfactants.

TEDX received information about 944 products used by gas companies through MSDS sheets and American Chemical Association CAS numbers. The CAS numbers were provided for a generic classification of the chemicals, but the actual chemical compounds and proportions are trade secret and will not be disclosed. The data made available lacked cohesiveness. TEDX assembled data on the human health and development effects in the following Figure 3.5.

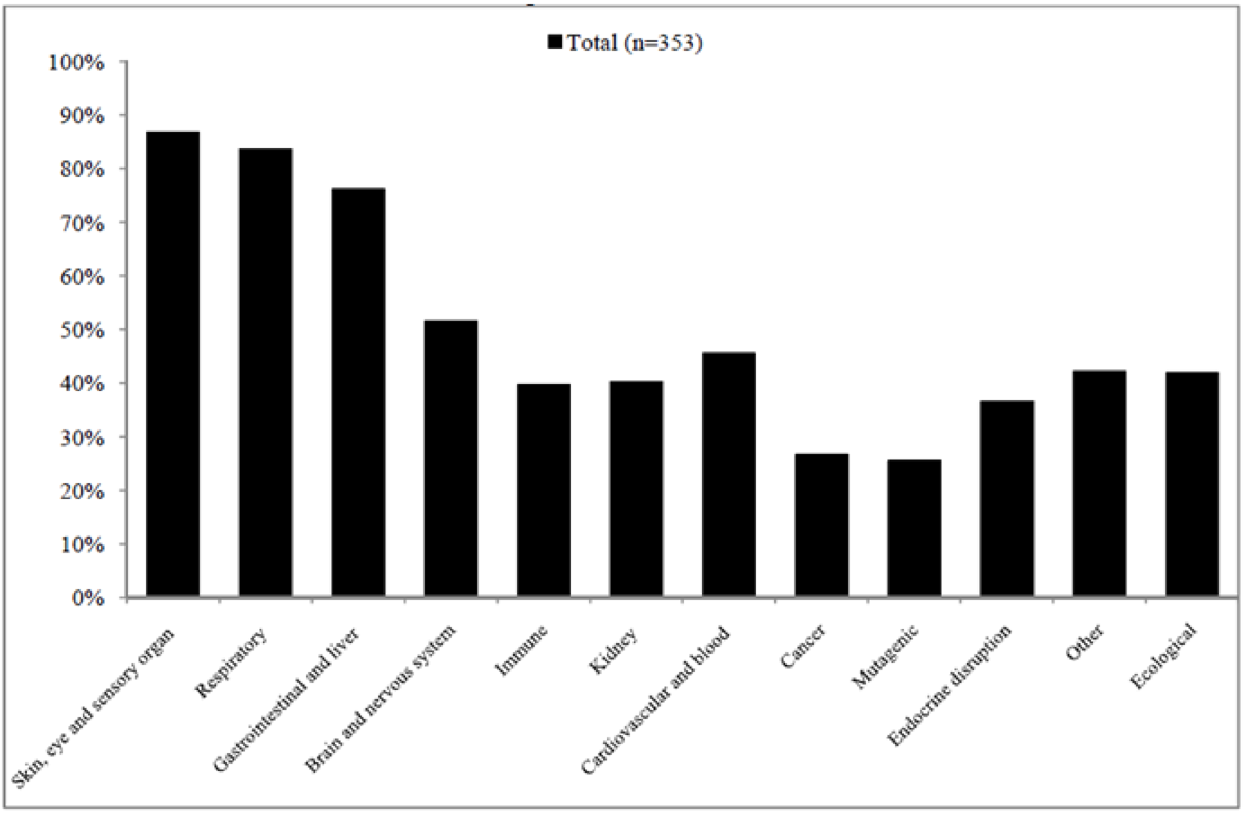


Figure 3.5: Health Effects from Fracturing Chemicals
Source: The Endocrine Disruption Exchange, 2010.

The three categories with the highest potential health effects from the chemicals are the skin/eye/sensory organ category, respiratory, and gastrointestinal and liver, followed by brain and nervous system. More than 75% of the chemicals affect sensory organs, respiratory, and intestines. About 45% can affect the nervous system, brain, and immune system. 37% affect the endocrine system, and 25% can cause cancer. They point out that the health effects of drilling operations are of long-term scope and are not immediately manifested. It is important to note that these health effects are measured only from the fracking chemicals, and do not reflect the health hazards of NORMs found in the flowback.

3.6 NORMs

The Marcellus Shale contains naturally occurring radioactive materials (NORMs), such as uranium. Geologists have used the distinct radioactive signature of the Marcellus Shale for years to differentiate it from other rock formations. Uranium decay products, such as radium, migrate from the formation into the fracturing flowback which then returns to the surface; the concentrations of radium depend on the characteristics of the formation which is being drilled. The higher the salinity of a formation, the more radium is mobilized into the fluid (WorldNuclear.org 2011). The Marcellus Shale has a higher level of salinity than most shales, and a higher level of intensive radioactive elements. In addition to the fracturing chemicals, flowback returns to the surface having picked up high amounts of Total Dissolved Solids (salinity), radioactivity, and heavy metals.

Ian Urbina of the New York Times drew public attention to the radiation hazard in his February 26, 2011 article entitled “Regulation Lax as Gas Wells’ Tainted Water Hits Rivers.” Urbina demonstrates through contaminant level spreadsheets that human risks associated with gas well drilling waste disposal “may be higher than previously disclosed.”

Water treatment plants are accepting millions of gallons of drilling waste. In some situations, the plant is not equipped to handle specialized wastes containing heavy metals, radium, and Total Dissolved Solids. In other situations, plants are not legally obligated to regulate certain effluents. This semi-treated water may then released into Pennsylvania’s streams, relying on dilution as the solution to the treatment issues, where it can be withdrawn only miles downstream for use as drinking water.

An article written by Ian Urbina of the New York Times entitled in February 2011, there were roughly 71,000 active gas wells in Pennsylvania. Urbina discovered that of the 65 drinking water intake plants in Pennsylvania, not even one plant had tested for radioactivity since 2008, and most had not since 2005. Most plants are not required to test more than every 6 to 9 years. As few as 6 years ago, there were only faint rumors of a drilling boom, and the wastewater was just starting to trickle into the system. Urbina found that Pennsylvania produced 1.3 billion gallons of hydraulic fracturing wastewater over the last three years. Twelve sewage treatment plants in three states were accepting this wastewater and discharging it into streams.

According to the EPA, "Radioactivity is the release of energy in the form of gamma rays and energetic particles (alpha and beta) that occurs when unstable elements decompose to form more stable elements." All of these forms release enough energy to break chemical bonds in living cells (2011).

The Marcellus shale is known to be rich in the elements in the Uranium-238 decay chain. The decay chain is seen in Figure 3.6. Elements in the decay chain of U-238 are various isotopes of uranium, thorium, protactinium, radium, radon, polonium, bismuth, thallium, mercury, and eventually lead.

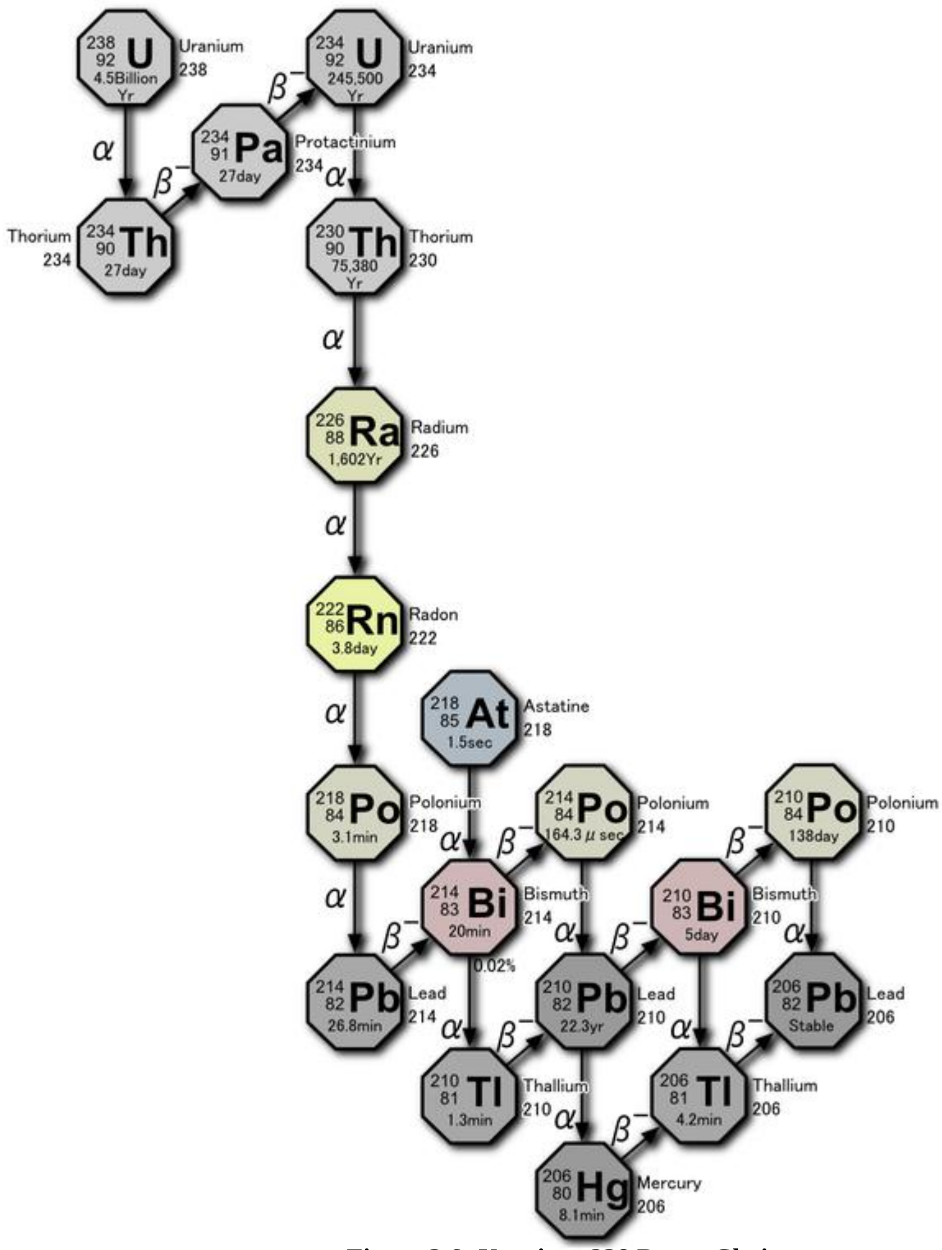


Figure 3.6: Uranium-238 Decay Chain
Source: HealthNewYork.gov, 2000.

The issue associated with the radioactivity of the water is that naturally occurring uranium decays into radium, which itself has many decay products. Radium decays by alpha elimination into radon, a gas that can be released into indoor breathing space from water by steam sources, such as showering and laundry. The pathway into the body is the most important consideration in determining radiation hazard. Inhalation is the most sensitive pathway for radon gas in humans. Radon further decays in the lung by alpha elimination into Polonium-218, which decays into other elements, all which have short half-lives (on the order of minutes or seconds) and release alpha and beta radiation. Gross alpha radiation (meaning that it releases a helium nucleus when it decays) can cleave both arms of the DNA helix. Simple barriers such as skin, or even a sheet of paper, are sufficient barriers to gross alpha radiation; however, alpha radiation is exceedingly more dangerous when inhaled. Once in the body, cell membranes cannot block the radiation and DNA becomes damaged.

Inhalation of radon gas is proven to cause lung cancer. After completion of a study proving beyond a doubt that radon causes lung cancer, Tom Kelly, former Director of the EPA's Indoor Environments Division said, "…breathing low levels of radon can lead to lung cancer." There is no safe limit for radon gas. Radon gas is the number one cause of lung cancer deaths among non-smokers. 21,000 lung cancer deaths each year are estimated from exposure to radon; that's out of 150,000 deaths due to lung cancer each year, a 14% portion (EPA 2011).

There are other potential health risks posed by other elements in Uranium-238 decay chain, such as uranium itself and radium. "Over a long period of time, and at elevated levels, radium increases one's risk of bone cancer and uranium increases one's risk of kidney damage." (HealthVermont.gov 2011).

The increased risk of bone cancer is due to the fact that radium behaves like calcium and is deposited in bones. It accumulates there and oxidizes healthy cells. Studies of workers who ingested radium show that it causes bone cancer. Smaller scientific endeavors have shown that ducks living around radium sources have brittle bones with high levels of radium in them.

The EPA regulates certain radionuclides in drinking water: (Adjusted) Gross Alpha Emitters, Beta Particle and Gamma Radioactivity, Radium-226 and -228 (Combined), and Uranium. Each of these contaminants, when consumed in excess of the Maximum Contaminant Level (MCL) has increased risks of causing cancer. These are summarized in Table 3.6.

Table 3.6: Environmental Protection Agency's Regulations for Radionuclides, 2011.

Radionuclides	MCLG	MCL
(Adjusted) Gross Alpha Emitters	Zero	15 picoCuries per liter
Beta Particle and Photon Radioactivity	Zero	4 millirems per year
Radium 226 and Radium 228 (Combined)	Zero	5 picoCuries per liter
Uranium	Zero	30 micrograms per liter

Information gathered by Urbina shows contaminant concentrations from 211 wells in Pennsylvania from 2008 to 2010. The reported waterborne contaminants include gross alpha, Ra-226 and Ra-228 levels, U-235 and U-238, as well as benzene levels. The average Gross Alpha Radiation of the reported wells is 4,857 picoCuries per liter. This is 323 times the amount of the EPA Standard of 15 picoCuries per liter.

Ridgway Borough's public sewage treatment plant in Elk County, PA accepts flowback for treatment. Discharge from this plant runs into the Clarion River. Paul McCurdy, the director of the treatment plant, was accepting about 20,000 gallons of fracturing waste water per day in 2009. Documents found by Urbina from gas companies in 2009 revealed the makeup of the waste that was sent to the Ridgway Borough plant that year. There was drill wastewater with radium higher than 275 times the drinking-water standard. Other types of radiation (which may include uranium) were over 780 times the drinking water standard. When Urbina asked McCurdy how he treated the radiation, McCurdy's reply was, "We count on state regulators to make sure that that's properly done." In order to limit their liability, these publicly owned treatment plants are doing what is legal – nothing more, nothing less. This is the precise reason why state regulations are paramount in the fight for community health rights.

On March 7, 2011, barely one week after Urbina's radiation article in the New York Times, he wrote a follow-up article entitled E.P.A. Steps Up Scrutiny of Pollution in Pennsylvania Rivers. This article opens by saying that the EPA had tested seven rivers in November and December of 2010 showing radioactivity "at or below" safe levels.

Interviewed by Urbina, Katy Gresh of the Pennsylvania DEP said that they are still considering where to take water samples in the future and whether to require testing at drinking water intake plants.

Conrad Volz, directed for the Center for Healthy Environments and Communities at the University of Pittsburgh is quoted saying "there needs to be monitoring weekly at least for a whole host of contaminants, including radium, barium, strontium." Even Senator Bob Casey supports the continuous testing of water because the concentration of drilling wastes can increase sharply in a drought.

Included in that list of other contaminants to monitor are levels of bromide. Bromide itself is a harmless salt compound found in Marcellus Shale flowback. If left untreated and discharged to streams, it combines with disinfectants such as chlorine at drinking water plants to create brominated trihalomethanes (THMs). Ingestion of THMs is linked closely with cancer and birth defects (Hopey and Hamill 2011).

3.7 Dilution Solution

Water quality experts within the gas industry defend the discharge of this radiation heavy water by saying that it will be diluted sufficiently by the volume of water moving through the river daily. Consider a hypothetical county in which gas drilling is especially thriving. This county relies on a one river for its fresh water needs. Peak construction season occurs mid-summer, when water levels are naturally lowest. Say a modest 10 wells are being fractured in a one week time period by various drilling companies who do not coordinate with one another, that's 50 million gallons of freshwater withdrawal, ignoring the water used in the initial drilling process. Say the flowback from these wells is trucked to a treatment plant upstream and then released, relying on natural dilution for treatment. The combination of too much water withdrawal from one river in the summer, with a treatment plant located upstream, can cause increased risk of reaching a toxic level for residents who may use it as drinking water. Certainly, these factors are not far off from becoming reality.

To take the hypothetical county to a real world example, the Monongehela River, in general, has much lower flow than the Susquehanna River, and a lot of drilling wastewater flowing through it. Its waters are more susceptible to toxicity because dilution factors fluctuate wildly. In 2008, the area surrounding Monongehela River experienced a drought. River levels were low and water withdrawals high for drilling and fracking activities. Waste water treatment plants upstream were discharging high volumes of water into the river without treating Total Dissolved Solids. These factors contributed to water coming out of faucets and bathtubs in a chunky state. Pittsburgh issued a warning for Pittsburgh residents to drink bottled water only. This is the manifestation of the fear of a low dilution scenario that scientists have been alluding to.

Chapter 4
Legislation

Legislation plays a vital role in every aspect of development of the Marcellus Shale. Waste water treatment plant operators monitor, filter, and discharge water according to the law, no more and no less. Power plants are being rebuilt in response to federal regulations regarding carbon emissions. The Marcellus Shale industry is composed of many businesses; as such, they make decisions based on cost. Setting environmental regulations at unattainable levels would prove as much a financial detriment to residents as would allowing environmental infractions to go unchecked. Legislation also determines minimum safety nets to protect citizens from environmental crises, and can force industries to enhance protections of drinking water supplies.

A lack of available, reliable chemical data was shown through TEDX's difficulty in compiling a list of health hazards associated with fracturing fluid chemicals. Proposed legislation seeks to correct these imbalances by revealing all chemical constituents and their proportions in fracturing fluids. Insufficient treatment processes combined with adverse conditions lead to citizens in Pittsburgh adhering to a bottled water only ordinance in 2008. Compounding this issue is too few regulators to oversee and enforce monitors.

These problems can all be solved through legislation. However, legislation often relies on taxes to bolster funds to make these programs possible. Pennsylvania currently has no tax on natural gas production. In fact, it is the only drilling state with no such tax. If implemented correctly, fair environmental legislation and a moderate natural gas production tax could ensure the safety and continued prosperity of Pennsylvania after the peak of Marcellus Shale natural gas production.

4.1 The Halliburton Loophole

Current legislation regarding the Marcellus Shale seems to be a retroactive method. After Urbina's radiation hazard article, monitors were placed on streams. After some other environmental issues such as the methane migration occurring in Dimock, Pennsylvania, more stringent casing regulations were adopted by the state and even by gas companies uninvolved in the investigation. These issues could have been prevented if sufficient federal standards were in order.

Due to the critical nature of natural gas as a fuel supply, to the ire of concerned residents, there appears to be historical exception to the oil and gas industry from landmark environmental laws. Interests in the oil and gas industry have been served by exemptions, exclusions, and agreements between the EPA and Congress. Some of these include immunities from environmental laws such as the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), Resource Conservation and Recovery Act (RCRA), and most importantly, the Safe- and Clean Drinking Water Acts. The most recent piece of legislation, the Energy Policy Act of 2005, introduces the so-called Halliburton Loophole to serve the natural gas industry.

The Energy Policy Act of 2005 was passed by Congress on July 29, 2005 and signed into law by President George W. Bush. Some general provisions of the act were to help homeowners and industry afford to transition to more alternative sources of energy, and transition to clean coal. One segment in this bill mentions hydraulic fracturing:

> "The term 'underground injection' -
> (A) **means** the subsurface emplacement of fluids by well injection; and
> (B) **excludes** –
>> (i) the underground injection of natural gas for purposes of storage; and
>> (ii) the underground injection of fluids or propping agents (other than diesel fuels) pursuant to hydraulic fracturing operations related to oil, gas, or geothermal production activities."

(EPA 2011).

This small segment of the Energy Policy Act of 2005 modifies the Safe Drinking Water Act's definition of "underground injection," preventing hydraulic fracturing operations from complying with the Safe Drinking Water Act (SDWA). The Safe Drinking Water Act is the basis on which the EPA regulates toxic chemicals from leaching into drinking water supplies. This segment is dubbed the Halliburton Loophole due to Halliburton's interest as the manufacturer of fracturing fluids, and the company's influence in the White House as Dick Cheney resided as Vice President.

“Injection wells” are regulated through the Underground Injection Control (UIC) program, which requires stringent adherence to the SDWA through permits, inspections, monitors, and frequent reports. Over 150,000 deep injection wells have been drilled in compliance with the SDWA. If hydrofracturing were performed with non-toxic substances or its application did not pose a direct threat to underground sources of drinking water, then this loophole would not be required to get around the SDWA. The federal level Fracturing Responsibility and Awareness of Chemicals Act (FRAC Act), proposed in 2009, seeks to close the Halliburton Loophole by requiring hydrofracturing operations to be considered “underground injection” and thus monitored and regulated under the SDWA; the second part of the FRAC Act would require disclosure of all fracturing chemicals before a spill emergency occurs.

One argument against setting federal standards on hydraulic fracturing is that state regulations could take precedence over them. However, while state regulation is not prohibited, it is not widely practiced. Only Alabama and Colorado have specific state regulations with respect to hydraulic fracturing. Alabama’s hydraulic fracturing protections were court ordered in 1997, while Colorado has set standards for chemical disclosure. If a federal standard were set under the Safe Drinking Water Act, it would provide a minimum that all states could use as a template for their own regulations (Environmental Working Group 2011).

4.2 Primacy

Proceedings in other states show why it is important to have a federal law covering hydraulic fracturing. For example, Alabama’s court ordered protections were due in part to the Environmental Protection Agency admitting that the hydrofracturing of coal bed methane posed a “growing potential for contamination of drinking water aquifers,” but not taking action to rectify the situation. In 1994, the Legal Environmental Assistance Foundation (LEAF) petitioned the EPA to revoke the Alabama UIC program’s right to regulate deep injection wells. LEAF cited the fact that Alabama’s UIC program was putting residents at risk by not complying with the SDWA while using hydraulic fracturing to extract coal bed methane.

The EPA said that nothing could be done because the definition of “hydrofracturing” was not included in the definition of “deep well injection” (and therefore not covered by Safe Drinking Water Act). Although the majority of fracturing fluid remains in the ground, the EPA said that the “principal function” of hydraulic fracturing was not “underground placement” and therefore was not covered by the UIC. LEAF appealed, and in 1997 the United States Court of Appeals, Eleventh Circuit, overturned the

EPA's refusal and mandated that hydraulic fracturing be covered under the Alabama UIC program, and successfully protected its residents' drinking water from coal bed methane extraction under the Safe Drinking Water Act.

States can apply for primacy (authority over the EPA's regulations of deep injection wells) by instituting a program as stringent as the federal program. States with existing oil and gas programs may make an optional demonstration in proving their program is effective in protecting underground sources of drinking water (EPA 2011). Figure 4.1 shows a map of which states do and do not have primacy over the EPA. Pennsylvania and New York do not have primacy, and would be required to adhere to federal regulations regarding deep injection wells until state regulations are set. If the FRAC Act were passed, this would set a minimum safeguard for all residents living in such states.

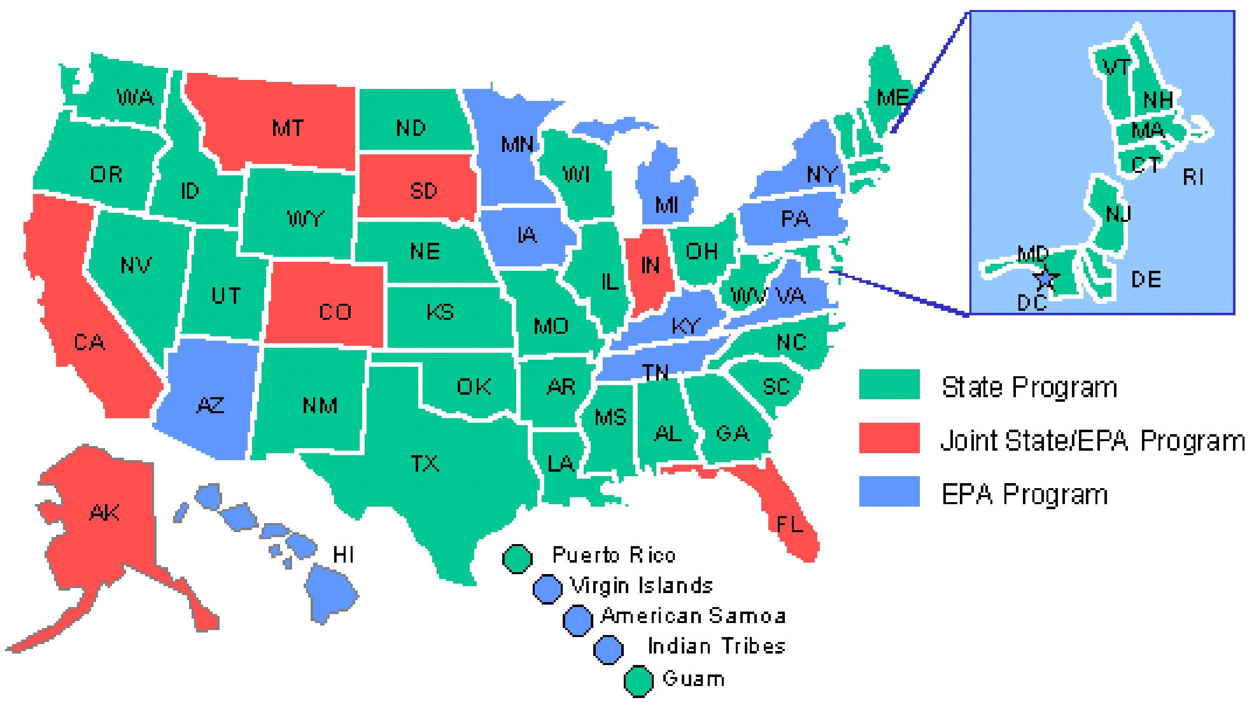


Figure 4.2: United States, Deep Injection Well Regulation Primacy
Source: Environmental Protection Agency, 2011.

When dealing with statewide regulation, one important consideration is that water pollution is a migratory problem. The distribution of pollutants in water can affect many people outside of the localized area where a toxic release has occurred, especially in situations of insufficient inspection and monitoring. Water travels in the path of least resistance, regardless of it being a state with lax regulation, or to a state with a moratorium. It can take hundreds of miles for pollutants to dilute sufficiently to pose no human health hazard; even in trace amounts, some pollutants such as heavy metals can accumulate in body tissues and cause permanent damage. Cities with drinking water downstream of Pennsylvania are concerned, especially the Chesapeake Bay watershed. Maryland has not allowed drilling within its borders within the last 15 years, but may be facing consequences from upstream gas production.

Tom Pelton of the Chesapeake Bay Foundation writes in the online newspaper The Bay Daily on current environmental events within the Bay. His article published on February 9, 2011 details an interview with a top Pennsylvania environmental official who recently resigned from his position in 2011.

Tom Quigley is the former Secretary of the Pennsylvania Department of Conservation and Natural Resources. He wrote in a letter to the Maryland General Assembly that they should be taking as much time as possible to consider the water quality impacts of drilling. Many people believe Pennsylvania is allowing the industry to grow without bounds, and the growing pains will be felt in our damaged waterways. He advised that Maryland take the same go-slow approach that New York is taking, and to look at Pennsylvania as a "cautionary tale."

Quigley also remarked that the influence of gas industry lobbyists on Pennsylvania's General Assembly is "shameful." They accept large contributions from lobbyists; some believe this has resulted in Pennsylvania being the only natural gas producing state with zero taxes on production.

4.3 The FRAC Act

As was previously mentioned, the Fracturing Responsibility and Awareness of Chemicals Act (FRAC Act) was introduced on June 9, 2009 by Diane DeGette, D-Colo., Maurice Hinchey, D.-N.Y., and Jared Polis, D-Colo. in the House of Representatives in an effort to close the Halliburton Loophole. The Senate version of the Act was introduced by Bob Casey D-Pa., and Chuck Schumer, D-N.Y.

Each state represented has an important stake in the future of shale gas, and each representative has a responsibility to protect the health of his citizens. The outcome of the FRAC Act may alter the course of regulation of hydraulic fracturing across the nation. Biding time may be critical as the NY DEC continues its research on Pennsylvania. When New York lifts the moratorium, it is likely that its citizens will be better protected by federal laws from the environmental issues associated with gas production.

The Independent Petroleum Association of America states that adhering to the regulations would result in a $100,000 capital increase to the price of each new well (2011). Setbacks such as a few days of schedule delay may cost more than that – for example, each day past a well pad's completion date costs the gas company $60,000. A drill rig is that expensive. A well can generate $16 million of gas production revenue in its 50 year lifetime. They threaten that this would make gas too costly to produce in states with such regulations. What would be too costly is to allow Pennsylvania to bear the financial burden of an environmental disaster due to a lack of evidence pointing to fracturing fluid migration from a non-"injection well" as the cause. If hydrofracturing and deep well injection are as safe as the industry explains, and their support of environmental stewardship is true and not just a public relations screen, then there should be no problem complying with the FRAC Act.

4.4 Taxation

Although regulations on hydraulic fracturing are not optimum, the fact is that gas production continues to grow in Pennsylvania at an unprecedented rate. Pennsylvania is making money from well permit fees and royalty taxes on residents. The industry has been proven to create a trickle-down effect, raising demand for manufactured steel, and consumer services and goods. Unemployment rates are as close to virtual zero in counties were natural gas production is highest. While these benefits are proven, the management of these funds is not optimum. The budget deficit had closed due to fees from the industry; but at any moment, the balance could falter and reopen the deficit. A well permit fee is a one-time fee. What will happen to these funds when fewer wells are permitted? Pennsylvania does not have a proper structure in place to appropriate these funds to ensure lasting prosperity.

Pennsylvania is one of only two natural gas producing states which have no severance tax on drilling – the other is New York, where no drilling is currently taking place. As of November 2011, over $263 million is estimated to have been lost by Pennsylvania since 2009 due to inaction in passing a severance tax on natural gas production.

The states with the highest gas production rates are Texas, Wyoming, Oklahoma, Lousiana, Colorado, and New Mexico. Each of these states produces over 1,300,000 MCF of gas per year, with Texas coming in at 6,818,973 MCF (The Pennsylvania Budget and Policy Center 2009). Each of these states has a severance tax.

Some groups claim that taxation would drive away the Marcellus industry from Pennsylvania. However, West Virginia imposes a severance tax of 6.1% and still has high gas production rates. Existing tax structures in states outside of the Marcellus Shale provide special provisions to make drilling economically feasible, such as exemptions for the first few years until capital investments are recouped. Louisiana, for example, taxes at a rate of $0.164 per MCF, with a two year exemption for horizontally drilled wells. Texas has a reduced tax structure for expensive wells at a rate of 3.7%, down from the standard tax of 7.5% of market value of gas produced. The definition of an expensive well could be worked out through negotiation with all parties involved.

In response to mounting pressures to act, Governor Tom Corbett is considering a “drilling impact fee” plan. This fee is introduced to help offset environmental impacts and raise money for various social programs Pennsylvania. The following Table 4.4 is excerpted from The Pennsylvania Budget and Policy Center’s Fact Sheet from November 2011, showing politicians’ support of total fee plans, and outlines the potential tax revenues per well and the effective rates.

Table 4.4: Pennsylvania Politician Total Fee Plans on Marcellus Industries
Source: The Pennsylvania Budget and Policy Center Fact Sheet, 2011.

Plan	Total Fee/Tax Revenue	Effective Fee/Tax Rate
Corbett/Ellis: HB 1950	$160,000 per well	1.0%
Scarnati: SB 1100	$360,000 per well	2.2%
Quinn: HB 1700	$710,000 per well	4.4%
Murt/DiGirolamo: A06344 to HB 1950	$755,000 per well	4.6%
Marcellus Shale Coalition Plan (August 2010)	$406,205 per well	2.5%

Corbett’s fee would collect $160,000 over the life span of an average Marcellus well, which is as long as 50 years. That is a small portion of the projected $16,000,000 in revenue generation over its productive life. In contrast to Corbett’s plan, the industry-supported Marcellus Shale Coalition’s 2010 Plan estimated their tax structure to generate $406,205 per well. In other states, Texas receives approximately $878,500 tax revenue per well. West Virginia receives approximately $993,700 per well, at an effective 6.1% severance tax rate. Tax proposals more favorable than Corbett’s are being presented by groups from all sides of the spectrum, even the industry itself. While his recognition of the plan’s necessity is a step in the right direction, there is still much more that could be done for Pennsylvania.

Pennsylvania Representative Thomas Murt says we are giving away a one-time resource by not taxing natural gas production. Murt and Representative DiGirolamo requested support of a natural gas severance tax on September 20, 2011. An imposed 4.9% severance tax on the gross value of production at the wellhead is proposed, which is still less than West Virginia’s tax.

If passed, DiGirolamo and Murt estimate the revenue to be $362 million in the first year and rise to $562 million by the fifth year. If natural gas production continues to grow at the anticipated rate, this number will only increase with time through 2020 and perhaps further. Taxation of natural gas production could provide funds for environmental monitoring, education, social programs, and prolonged prosperity at local and state levels.

Chapter 5

Summary

Oil and coal production in Pennsylvania is well established, so it is not difficult to believe that Pennsylvania has acquired a different legacy in another realm of fossil fuels: natural gas. The Marcellus Shale is an unconventional gas play, and only recently became accessible through mechanical stimulation technologies.

High levels of natural gas production from the Marcellus Shale draw attention on a national scale. The Marcellus Shale brings a cleaner fossil fuel to market at a lower price per thermal unit than coal or oil, with significantly reduced carbon dioxide and virtually no particulate or mercury emissions. Gas extraction stimulates the economy by creating jobs, reviving industry, and contributing funds to the state's revenue via well permit fees and royalty taxes. From reputable gas company endorsements, it appears that this thriving industry will remain in Pennsylvania for many decades.

Despite earlier geological exploration and accounts of natural gas extraction spread throughout Pennsylvania's history, we are the first generation of Pennsylvanians living with a booming natural gas industry. A major drawback to production of the Marcellus Shale is that the technology associated with it has the potential to soil underground drinking water sources. The first decade of drilling in the Marcellus brought many issues to light. In the beginning there were various environmental issues including illegal fluid discharges, methane migrations due to poor casing and cementing implementation, and poorly enforced, unmonitored effluent levels from water treatment plants. However, these concerns have been dealt with by appropriate government agencies and responsible gas companies.

Concerns still exist regarding the treatment of fracturing fluids by waste water treatment plants, which could leave surface waters with untreated carcinogenic chemicals, high alpha-radiation emitting elements, heavy metals, and high levels of bromide salts, which can form trihalomethanes. All of these pollutants have human health risks.

While environmental legislation pushes closer to sufficient protection, there are still exclusions for the oil and gas industry from landmark environmental laws. Included is the so-called Halliburton Loophole which exempts hydraulic fracturing from regulation under the Safe Drinking Water Act. Closing these gaps in legislation with the FRAC Act would serve to federally regulate hydraulic fracturing and would provide a minimum safety net for Pennsylvanians and other residents receiving water from its streams. New legislation involving the creation of a moderate tax on natural gas production would further increase funds for Pennsylvania. After the peak of the gas drilling boom, these funds could ensure the continued growth and prosperity of Pennsylvania.

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