NYS Hydraulic Fracturing Waste Tracking Program

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NYS Senate Bill 6892-2011: The High-volume Hydraulic Fracturing Waste Tracking Program

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Executive Summary

The passage of New York State Senate Bill 6892-2011, the High-volume Hydraulic Fracturing Waste Tracking Program is necessary to establish a foundation for regulation on forthcoming natural gas extraction from the Marcellus basin in New York State. While a moratorium currently restricts fracturing activity in New York, enticing economic implications that imply development of these resources is imminent. New York State Senate Bill 6892-2011 addresses concerns of environmental contamination caused by hydraulic fracturing, however, uncertainties still linger. This report provides thorough analysis of the science associated with high-volume hydraulic fracturing, and provides recommendations for subsequent policy and research. New York State Senate Bill 6892 is an important advancement towards a solution for safer extraction recognizing that natural gas is rising as a predominant national energy resource.

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Introduction

The use of natural gas as an energy source has dramatically increased around the world since the end of World War II. It currently accounts for about 21% of the global energy portfolio and is the third largest source of primary energy after coal and oil (IEA, 2011; Wright, 2012). The United States of America consumed 23.38 trillion cubic feet (tcf) of natural gas in 2008, making it the world's largest consumer, followed by the entire European Union at 18.93 tcf and Russia at 16 tcf (IEA, 2011). Natural gas extraction from unconventional sources, such as gas trapped in shale formations, has been a "game changer" in the composition of the United States' energy portfolio and energy outlook because of the combination of two technologies that made it economically viable to develop: hydraulic fracturing and horizontal drilling (WEC, 2012). The economic, energy security, and environmental benefits of gas are significant enough that it is highly likely that unconventional sources of natural gas, such as the Marcellus shale formation in the northeastern United States of America, will continue to be developed. However, there is strong opposition from stakeholders who claim that hydraulic fracturing is a risk to public health and the environment (IEA, 2012). In an effort to reconcile differences between key stakeholders, including those who want to develop the massive Marcellus shale formation in New York and those concerned with public health and the environment, the New York State Senate introduced Senate Bill 6892 on April 4th, 2012 (S6892, 2012). This bill establishes a waste tracking system to monitor and disclose the contents of the fracturing fluid that returns to the surface, which the bill defines as hazardous waste (S6892, 2012). This analysis will examine Senate Bill 6892's potential effectiveness and limitations.

The Advantages of Natural Gas

Natural gas's success as an energy source is a result of the advantages it has over other fossil fuels such as coal and oil, as well as over nuclear, hydroelectric, and renewable energy sources. Natural gas burns much cleaner and with fewer environmental pollutants than coal or oil due to its simpler chemical structure (Tertzakian, 2006). Coal and oil both produce more carbon dioxide, pollutants, and particulate matter per million British Thermal Units (Btu) of energy than gas (Goldstein, 2004). In fact, natural gas produces 47% fewer greenhouse gas emissions than coal when emissions are accounted for from source through ultimate use (Mellquist, 2011). Although natural gas still produces a large quantity of greenhouse gases compared to renewable or nuclear energy, it is less expensive to develop, which gives it a market advantage over renewables (BP, 2012; EIA, 2010). Moreover, natural gas currently produces electricity at about the same retail cost per kilowatt hour as coal, and is substantially less expensive than nuclear, solar, or wind power (Mellquist, 2011). Consequently, natural gas is a relatively inexpensive way to reduce carbon dioxide emissions and pollution.

Despite high levels of natural gas consumption in the United States, European Union, and Russia, as well as large projected increases in consumption, especially in developing countries, there are enough proven reserves of natural gas to support global demand for more than a century (IEA, 2012). The International Energy Agency estimates that globally there is as much unconventional gas, i.e. gas trapped in shale formations or tight gas formations, as there is conventional natural gas (IEA, 2011). Moreover, although conventional gas reserves are focused in only a small number of countries, unconventional gas resources are more evenly distributed around the world; every region[1] has at least a 75 year supply of combined conventional and unconventional gas (IEA, 2011).

The United States is estimated to have 482 tcf [2] of technically recoverable shale gas, 140 tcf of which are in the Marcellus shale in New York, Pennsylvania and surrounding states (EIA, 2012). Aside from the Marcellus shale formation there are also large shale gas

Figure 1: Shale gas reserves in the United States (EIA, 2012).

[1] The IEA defines seven regions: OECD North America, Latin America, OECD Europe, Eastern Europe/Eurasia, Africa, Middle East, and Asia Pacific (IEA, 2011)

[2] These estimates, by the U.S. Energy Information Administration (EIA) are significant downward revisions from 827 tcf total reserves and 410 tcf of gas in the Marcellus shale last year due to new survey methodologies (EIA, 2012) (WEC, 2012).

reserves throughout the contiguous 48 states (EIA 2, 2012). This is another significant advantage natural gas has over oil, which BP suggests has a ratio of production to proven reserves of 54.2 years globally at 2011 production rates (BP 2, 2012). However, it was not until recently that unconventional sources of natural gas were economically feasible to develop.

Hydraulic Fracturing and the Marcellus Shale Potential

The United States has been one of the world's leading producers of natural gas for several decades, but recent advancements in hydraulic fracturing, also called fracking, and horizontal drilling have allowed for rapid expansion in domestic production. Hydraulic fracturing is a process in which water, sand, and chemicals are injected into a well at extremely high pressure in order to fracture shale formations. The fractures release natural gas, water, and sometimes oil or natural gas liquids that were trapped within pockets in the shale (IEA, 2012). Without fracturing, shale formations would be uneconomical to develop. Hydraulic fracturing had been practiced since 1949, but it remained relatively cost-prohibitive until the late 1990s when Mitchell Energy & Development Corp. developed a way to use "slick water" as a fracturing fluid instead of gels, which greatly reduced the cost of fracturing (YSI Environmental, 2011; Geny, 2010).

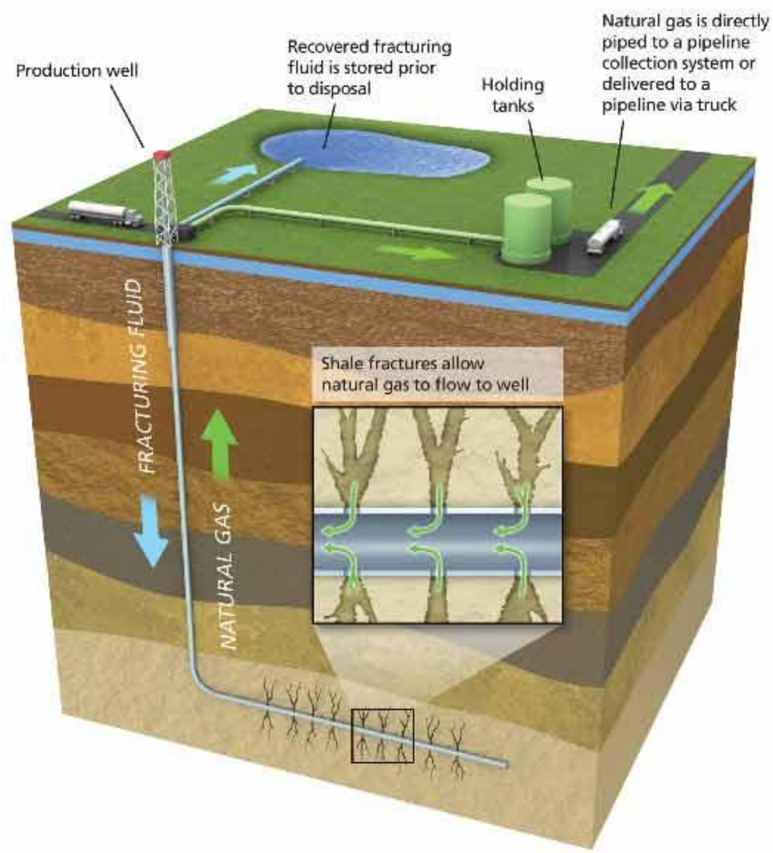

Figure 2: The hydraulic fracturing process (Studiosayers, 2011)

Horizontal drilling is an advanced drilling technique that allows well operators to drill horizontally underground, in addition to vertically. Horizontal drilling allows a single well to access a larger portion of a gas formation and thus fewer wells are needed on the surface (ANGA, 2012). Although horizontal drilling has been available for several decades, shale gas production was not economical until Devon Energy's technological breakthrough in 2002 of combining slick-water hydraulic fracturing with horizontal drilling (Pless, 2012; Geny, 2010; Steward, 2011). Thus, the combination of hydraulic fracturing and horizontal drilling has allowed a huge new resource of natural gas to become recoverable at a competitive price[3].

The Marcellus shale is the largest shale reserve in the United States. It covers approximately 140,000 square miles in seven states, ranges in depth from being exposed at the surface to 7,000 feet underground, and is relatively undeveloped (NYSDEC, 2011). The 140 tcf of gas in the Marcellus shale alone could supply

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[3] For a full timeline of the development of hydraulic fracturing see Appendix 4 on page 30.

the United States with gas for nearly six years. Furthermore, the economic potential of the gas trapped in the Marcellus shale could be worth two trillion dollars, which represents a clear incentive for energy companies to develop this resource (ANGA, 2012).

Another economic advantage of the Marcellus shale formation is that it lies near large urban centers along the East coast which use large amounts of natural gas. This location reduces the cost of transporting the gas. Natural gas production potential from the Marcellus shale is production is great enough that, in New York alone, the New York State Department of Environmental Conservation (NYSDEC) predicts that an average of 1,600 wells could be hydraulically fractured per year for up to 30 years (NYSDEC SGEIS, 2011). The United States has the potential to increase its unconventional natural gas production by more than 60 percent by 2035, at which point natural gas consumption will have surpassed coal consumption as the second largest energy source in the United States (IEA, 2011).

There are many advantages to developing the Marcellus shale formation beyond the economic benefits for the companies involved. Increasing the proportion of natural gas in the United States energy portfolio at the expense of coal or oil would benefit the environment and human health because natural gas releases less carbon dioxide, far fewer smog-producing compounds, no mercury, and very few fine particulates when burned (Pless, 2012). On the other hand, natural gas is comprised of methane, a greenhouse gas with 20 times the heat trapping capacity of carbon dioxide (Pless, 2012). Thus, should natural gas wells leak, they could contribute significantly to global warming. Despite this risk, natural gas is generally seen as an important transition fuel for the development of low-carbon economies (Mellquist, 2011). Another environmental advantage of combining horizontal drilling with hydraulic fracturing is the reduced impact on the surface compared to traditional gas, oil, or coal extraction. A single well pad can drill six to eight wells resulting in a surface footprint of around seven to eight acres, compared to 640 acres required to achieve the same extraction results with vertical wells (NYSDEC SGEIS, 2011).

The expansion of natural gas production also has implications for energy independence. Unlike the fungible global market that controls oil prices, two thirds of natural gas is still consumed in the country that produces it. Furthermore, natural gas is transported mostly along regional pipe networks, or, to a lesser extent, as liquefied natural gas (IEA, 2010). Consequently, gas markets are highly regionalized and relatively isolated from one another. For example, gas can cost three times more in Japan than it does in the United States (IEA, 2010).

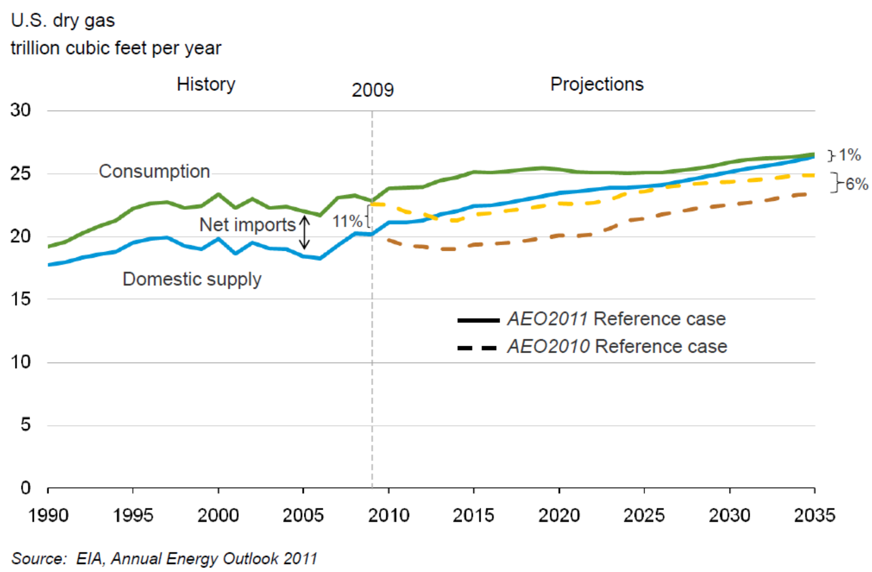


Figure 3: U.S. natural gas import projections (OECD, 2011)

Because the United States stands to substantially increase production of natural gas, mostly from unconventional shale gas, it could begin exporting large amounts of liquefied natural gas by the year 2035 (Siegel, 2012). Thus, the United States may achieve natural gas energy independence.

New York in particular stands to gain economically from Marcellus shale production. New York is the fifth largest consumer of natural gas in the United States, but in 2010 it produced less than four billion cubic feet (bcf) of gas compared to over 60 bcf in neighboring Pennsylvania (Shafer, Williams, & Mook, 2012; EIA Penn., 2012; EIA NY., 2012). The proportion of the Marcellus shale that is located in New York holds approximately 40 tcf of natural gas, which is less than half of Pennsylvania's 88 tcf, but the estimated amount of gas each well could produce is the same in both states (EIA, 2012; EIA, 2011). The low level of production in New York is due to a moratorium on all hydraulic fracturing within the state as a result of concerns over the health and environmental risks posed by hydraulic fracturing (Klopott & Efstathiou, 2012).

New York would see a significant amount of industrial investment, an influx of jobs in the natural gas industry, and increased tax revenue if the moratorium was lifted. For example, in Pennsylvania the natural gas industry employed approximately 111,000 employees and generated approximately 10 billion dollars in economic value through these jobs and the payment of taxes (Considine, Watson, & Blumsack, 2010). Analysts estimate that the economic value generated by shale gas extraction in Pennsylvania could reach 20.2 billion dollars in 2020 (Range Resources, 2011). Energy consumers could also

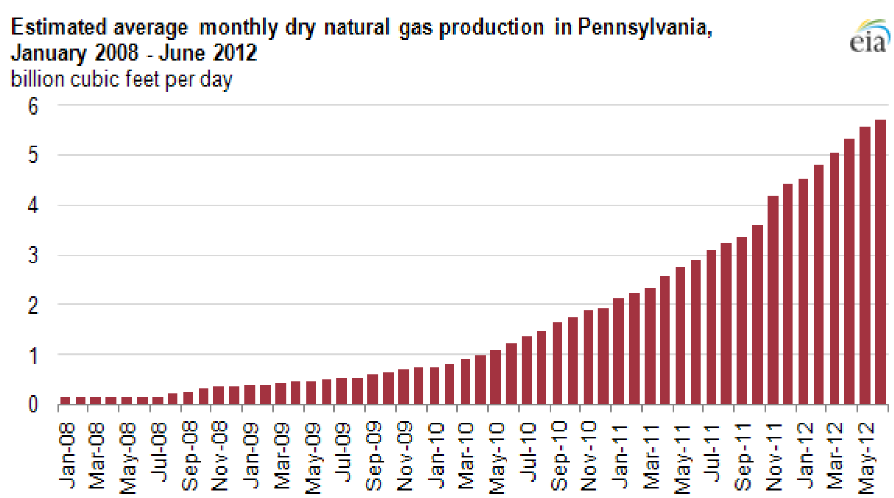


Figure 4: Total Pensylvania natural gas production (EIA 3, 2012).

benefit in New York through lower energy costs. In 2010, consumers in Pennsylvania paid 245 million dollars less than in 2009 for natural gas and electricity produced from natural gas (Range Resources, 2011). Moreover, this development could occur rather rapidly as it did in Pennsylvania. Production in northeastern Pennsylvania passed 2 billion cubic feet of natural gas a day in 2011, five times what Pennsylvania was producing in 2010 (EIA 2, 2011). As such, there are strong economic incentives for hydraulic fracturing development of the Marcellus shale formation in New York.

Opposition to Hydraulic Fracturing

Hydraulic fracturing has generated a substantial opposition from environmental groups and citizens because it is relatively poorly understood by the wider community, and widely believed to be unsafe due to the large quantities of chemicals used in the hydraulic fracturing fluid (often referred to as fracking fluid). Hydraulic fracturing uses a very large amount of water, and the sheer number of wells drilled has created environmental concerns (Steingraber, 2011). In New York, the number of wells drilled doubled between 2000 and 2008 without sufficient assessments of public health or environmental impacts, which added to public skepticism (Finkel & Law, 2010). In response to these concerns, New York placed a moratorium on new drilling permits until the hydraulic fracturing process and its impacts could become better understood (Klopott & Efstathiou, 2012).

Fracking fluid is typically composed of 98% to 99.5% percent water and sand and the remaining 0.5% to 2% is a mixture of chemical additives (GWPC, 2009). The sand is used as a "proppant" designed to hold open the fissures in the shale during fracturing and prevent them from sealing again once pressure is removed (IEA, 2012). The amount of water used to fracture a well varies from location to location, but the two main factors contributing to the amount of water needed for fracturing are the depth of the well and the number of fracturing stages required for the well (GWPC, 2009). The average amount of water needed to fracture a well in the Marcellus formation is 3.88 million gallons[4], but can range from two million to eight million gallons total (GWPC, 2009). These figures include the 80,000 gallons of water required to drill the well itself, which is less water than is required to drill other formations (Veil, 2010)[5]. This volume of water, if brought to the well with trucks, is the equivalent of approximately 500 truckloads (IEA, 2012). The amount of truck traffic required to provide a well with water is another source of concern to local communities due to the noise, vehicle emissions, and traffic congestion that can result.


Figure 5: Marcellus shale hydraulic fracturing operation in West Virginia (GWPC, 2009).

The large volume of water required for each well fractured and the large number of wells drilled in each shale formation has led to significant concern among local communities about potential

[4] This is more than hydraulically fractured wells in the Barnett, Fayetteville, or Haynesville shale formations which use 2,300,000 gallons, 2,900,000 gallons, and 2,700,000 gallons of water respectively for fracturing (GWPC, 2009).
[5] Barnett uses 400,000 gallons, Haynesville uses 1,000,000 gallons, but Fayetteville uses only 60,000 gallons (GWPC, 2009).

water conflicts should the water used for fracturing be extracted locally rather than trucked in from other locations (Veil, 2010). For example, the Barnett shale in Texas is the most mature shale play in the United States and had more than 13,500 wells completed between 1997 and 2009 (OECD, 2011). If the same number of wells were drilled horizontally and fractured in the New York portion of the Marcellus shale formation, it would require approximately 52.38 billion gallons of water. Although this volume of water is small compared to water extraction for electrical generation or agriculture, it could pose threats to water security in areas with existing water shortages (GWPC, 2009; IEA, 2012; Schneider, 2011).

In addition to concerns about water quality, hydraulic fracturing introduces a number of chemicals that could compromise water quality. These chemicals have a number of uses: killing bacteria that cause corrosive byproducts; causing the mixture to become viscous enough to keep the sand suspended; preventing the mixture from breaking down or losing its viscosity under pressure and heat; reducing friction; preventing formation clays from swelling; preventing the precipitation of metal oxides that lead to iron build up; adjusting the pH level of the fluid; and other tasks that improve the efficiency of the fracking fluid (Chesapeak, 2012; FracFocus, 2012). The type and ratio of each chemical additive changes with each fracturing operation based on the unique geology of the well. The total volume of chemical additives added to fracking fluid change with each well based on the quantity of water and sand used.

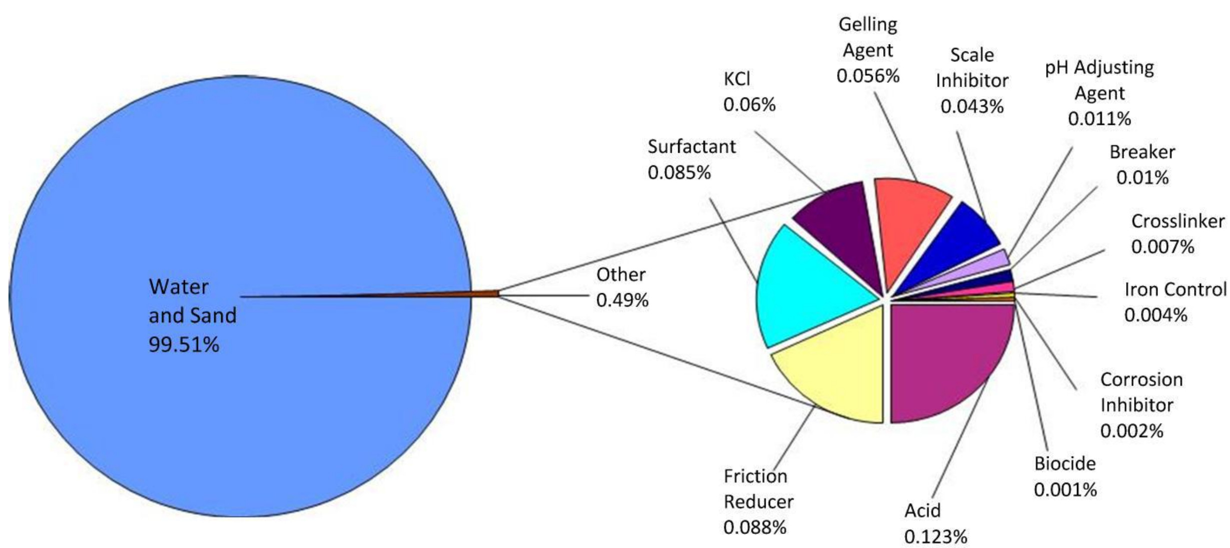


Figure 6: Composition of fracturing fluid used in the Fayetteville shale formation (GWPC, 2009)

One of the main sources of concern of those opposed to fracturing is that some of the chemicals used in fracturing fluid are toxic. Furthermore, many stakeholders know that the chemicals are considered trade secrets, which means that gas companies do not need to release details about the chemicals they use to the communities near hydraulic fracturing sites (Mall, 2007). Furthermore, most wells are excluded from the disclosure requirements under the Right to Know Act. Since gas companies typically store less than 10,000 gallons of chemicals on site, they do not need to release statistics to the public regarding which chemicals and chemical concentrations they use (Mall, 2007). Another major concern of fracking opponents is that the chemicals used in hydraulic fracturing are not adequately regulated. Currently, the chemicals used in hydraulic fracturing are exempt from federal hazardous waste regulations under the Environmental Protection Agency (EPA, 2002).

There is significant public concern that the hydraulic fracturing fluid used to create fissures in the shale formation will contaminate underground aquifers and the surrounding environment (NYSDEC 2, 2011). Inadequate well casing, poor cementing, fluid tank ruptures, accidents during fluid transport, and failure to address surface water issues can result in the release of fracking fluid into the immediate environment (NYSDEC 2, 2011; University of Texas, 2012). In addition, floodwater and storm water surge could result in fracking fluid runoff if proper containment measures are not in place (NYSDEC 2, 2011).

The Science of Hydraulic Fracturing and the Marcellus Shale Potential

There are various chemicals in hydraulic fracturing fluid that present potential risks to human health and the environment (NYSDEC 2, 2011)[6]. On type of chemical additive is biocide, or agents that destroy shale-dwelling organisms (Endo, 2006). Glutaraldehyde is a biocide in fracking fluid that is known to cause genetic mutation, induce occupational asthma, and cause damage to blood, the reproductive system, liver, mucous membranes, the spleen, central nervous system, and exocrine system (Endo, 2006; MSDS, 2012). Other chemical additives in fracturing fluid act as endocrine disruptors which are known to have dangerous human health effects at even low levels of exposure (EPA, 2012). Endocrine disruptors, such as arsenic, mimic natural hormones in the human body and are linked to cancer of the bladder, lungs, skin, kidneys, liver, and prostate (EPA, 2012).

The chemicals used in fracturing pose a risk because a significant proportion of the fracturing fluid returns to the surface after fracturing. The New York State Department of Environmental Conservation estimates that in Pennsylvania only 9-35% of the total fracking fluid injected into the shale rock during the fracking procedure returns to the surface (NYSDEC 2, 2011). The fluid that returns to the surface is called "flowback fluid" or "wastewater" (EPA, 2012). Flowback fluid contains the initial chemical additives found in the original injection fluid as well as new substances mobilized from the shale formation that come to the surface with the flowback fluid (NYSDEC 2, 2011). After the fluid reaches the surface, it is typically held in storage tanks or open waste impoundment pits prior to treatment, recycling, and disposal (EPA, 2011).

Flowback fluid also contains naturally occurring toxins it acquired from the shale before returning to the surface. These naturally occurring toxins include salts, heavy metals, liquid hydrocarbons, and radioactive elements (Bishop, 1999). Benzene is a carcinogen that is commonly found in flowback fluid (Bishop, 1999). A carcinogen is defined by the Environmental Protection Agency as "a chemical or physical agent capable of causing cancer" (EPA 3, 2012). Benzene is also toxic to blood, bone marrow, and the central nervous system, and is associated with organ failure in people exposed repeatedly or for prolonged periods of time (MSDS 2, 2010). Radium is another carcinogen often found in flowback fluid (Bishop, 1999). When ingested, this radioactive chemical can cause leukemia, lymphoma, and bone cancer (EPA 3, 2012). The New York State Department of Environmental Conservation estimates that flowback fluid contains radium concentrations 200 times greater than the safe limit for discharge into the environment, and more than 3,000 times greater than the United States Environmental Protection Agency drinking water standard" (Lustgarten 1, 2009).

[6] To see a list of known chemical additives, their uses, and where they are used aside from for fracturing, see Appendix 2 on page 28.

Along with human health effects, contamination from flowback fluid can have adverse ecological effects. Arsenic and benzene are toxic to birds and aquatic life, resulting in chronic effects that include shortened lifespan, reproductive problems, and diminished fertility (NPI, 1992; Colborn Theo, 1993). Glutaraldehyde has been found to dramatically decrease algae, zooplankton, and steelhead trout populations (L. Larissa, 2004). Some chemicals found in the flowback fluid, such as radium, can be biomagnified through the food chain, resulting in organisms higher in the food chain having increased concentrations of the chemical in their tissue, which also increases the risk to human health when humans consume the higher order organisms (Lenntech, 2011). In addition, many of these chemicals can damage or kill plants, including agricultural crops (NPI, 1992).

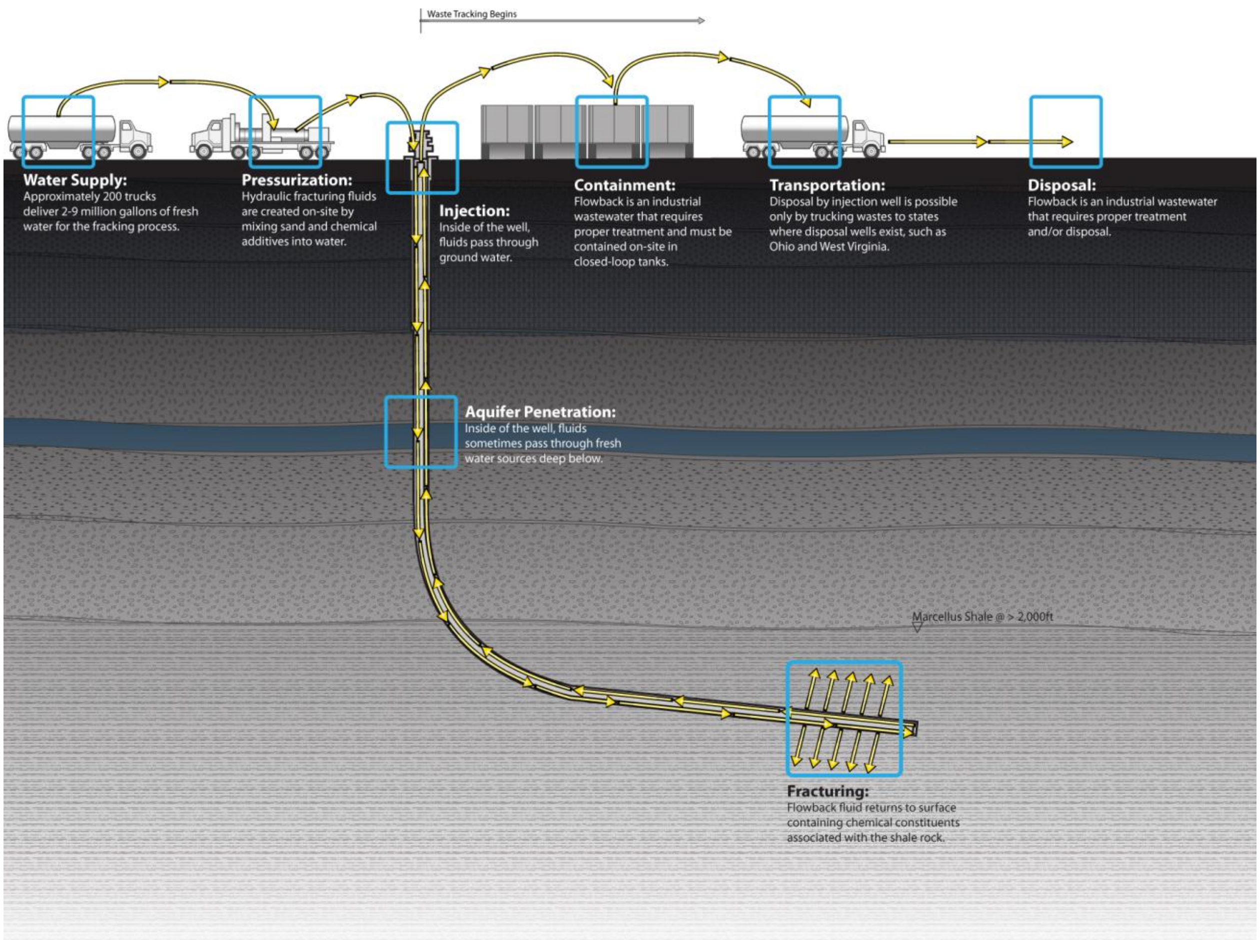


Figure 7: Movement of fracturing fluids (Graphic: Fernando Arias).

Fears that local water supplies, groundwater, and the air could become polluted by hydraulic fracturing are compounded by the lack of regulation and transparency in the process (IEA, 2012). Concern regarding water contamination led to calls on the State to impose a moratorium on drilling. However, there are significant economic incentives associated with moving forward in developing the Marcellus shale. The International Energy Agency, an international energy policy think tank, argues that developing unconventional natural gas has the capacity to be a "game-changer" in the energy industry, but only if society can accept hydraulic fracturing as a safe and socially responsible technology (IEA, 2012). In order earn a "social license to operate," the natural gas industry must be well regulated, transparent, and committed to environmental protection (IEA, 2012). Consequently, in order to provide protection for human health, and to lift the moratorium and allow for gas development, New York State Republican Senators Mark Grisanti and Stephen Saland introduced Senate Bill 6892: creating the high-volume Hydraulic Fracturing Waste Tracking Program to the Senate floor on April 4th, 2012 (S6892, 2012).

Stipulations of Senate Bill 6892

New York State Senate Bill 6892 amends Article 23, "Mineral Resources," of the current Environmental Conservation Law by adding Title 25: Creating the High-volume Hydraulic Fracturing Waste Tracking Program (S6892, 2012). This amendment addresses the tracking and monitoring of waste produced through the process of high-volume hydraulic fracturing in the state of New York. As identified by the New York State Department of Conservation, solid and liquid waste transport and disposal from high-volume hydraulic fracturing is a recognized threat to the surrounding environment (NYSDEC SGEIS, 2011). The Department, which regulates mineral resources activities within the state, will be required to ensure that the owners and operators of natural gas extraction companies carefully oversee the monitoring of waste management processes.

The bill stipulates that the waste tracking program shall:

a) Provide for the tracking of the transportation of liquid and solid waste associated with the production of natural gas where high-volume hydraulic fracturing is utilized;
b) Include a system for providing the generator with assurance that the materials were treated or received by the receiving facility;
c) Use a uniform form or forms for tracking;
d) Require the generator to deliver a copy of the manifest form to the department when the shipment leaves their facility site;
e) Require receiving facility to deliver a copy of the manifest form to the department when the shipment arrives at the receiving facility;
f) Use a computer system to maintain a record of data from the manifests and track the movement of liquid and solid waste; and
g) Display data records on the department's website.

The bill defines high-volume hydraulic fracturing as processes that involve the injection of more than 300,000 gallons of water in a well in any direction: horizontal, vertical, or directional (S6892, 2012). According to the Supplemental Generic Environmental Impact Statement issued by the Department, wastewater resulting from the hydraulic fracturing could adversely impact the surrounding environment (NYSDEC SGEIS, 2011). The United States Environmental Protection Agency has also noted that the wastewater could have negative impacts on drinking water resources (EPA 2, 2012). As a regulatory measure to prevent environmental degradation, the bill has been designed to monitor the generation, movement and disposal of liquid and solid waste produced as a by-product of high-volume hydraulic fracturing in New York.

All definitions for Sec. 23-2501 are defined in the body of the bill, as taken from Article 23 of the Environmental Conservation Law and have been referred to within this report to optimally interpret the legislation and analyze the effectiveness of the bill within an environmental policy framework. Definitions can be found in Appendix 1 on page 27.

Science of the Solution

The bill states that the New York State Department of Environmental Conservation should "use a more robust tracking system similar to that which is used for hazardous waste" (S6892, 2012). The Department is responsible for administration and enforcement of the Environmental Conservation Law. As such, one of the key responsibilities assigned to the Department, includes "[regulating] the disposal, transport and treatment of hazardous and toxic wastes in an environmentally sound manner" (S6892, 2012).

The proposed tracking system would require all owners and operators of oil or gas well pads, whose acts or processes produce or receive solid or liquid waste, to report to the Department through the format of a manifest protocol. The manifest identifies the "quantity, composition, origin, routing and destination" of the waste from point of generation through the point of disposal (S6892, 2012). This information would not only make the movement of waste transparent but would also require natural gas companies to provide the exact composition of high-volume hydraulic fracturing waste products so that associated risks can be better understood.

Figure 8: Hydraulic fracturing site in Pennsylvania (GWPC, 2009)

Under the bill, the New York State Department of Environmental Conservation will store and maintain all data records of waste tracking and provide electronic accessibility of these records to the general public. New York currently tracks the movement of hazardous waste generated and managed in the State from "cradle to grave", defined by the Department as "from when it leaves the place of generation until it gets to the place where it is managed" (NYSDEC 2, 2012). The current hazardous waste tracking system, which is not yet utilised in the high-volume hydraulic fracturing industry, is entitled the "Uniform Hazardous Waste Manifest Form" and, as stated by the Department, is a "chain-of-custody form used to track the generation, transportation and receipt of hazardous waste" (NYSDEC 2, 2012). This form is stated to "travel with the hazardous waste and must be signed by the generator, transporter, and the receiving facility" (NYSDEC, 2011). This form is a national protocol and was first introduced in 2006, with state-specific regulations where applicable. As outlined by the New York State Department of Environmental Conservation, the manifest form includes information on the Generator, Transporter, and Treatment, Storage and Disposal Facility, the hazardous waste type, hazardous waste quantity, and how it will be managed.

Advantages of Senate Bill 6892

The requirements of the bill create a set of beneficial conditions for safely managing hydraulic fracturing. New York Senate Bill 6892 defines the fracturing fluid that returns to the surface as hazardous waste, thus it is not until the fluid returns to the surface that the "cradle" part of the "cradle to grave" tracking process begins (S6892, 2012). In Pennsylvania, flowback fluid is currently handled in several different ways. Most of the flowback fluid is treated and reused, but approximately six percent of flowback fluid is injected into underground wells, one percent is sent to publicly owned treatment works, one percent is sent to landfills, and the destination of four percent is unknown (PADEP, 2012). Most of the hydraulic fracturing fluid that returns to the surface as flowback fluid will do so within a relatively short period of time and can be treated and reused in other wells (Cornell, 2012). Flowback fluid that takes longer to return to the surface, or natural formation water that returns to the surface, typically cannot be reused as a result of the lower volume and longer times involved. Because industrial treatment is impractical, the flowback fluid is stored onsite until it can be treated (Rahm & Riha, 2 0 1 2).

While awaiting treatment, most of the flowback fluid in Pennsylvania is stored in open storage pits (NYSDEC 2, 2011). The fluids in these pits have been reported to potentially release toxic vapors such as benzene and toluene (Steingraber, 2011). These pits are typically near the wells and represent one of the first routes of contamination. Excessive precipitation could cause poorly designed pits to over flow; design flaws could cause the pits' containment walls to collapse; or the waterproof bottom liners on the pits could tear, allowing wastewater to percolate into the ground. If any of these events occur, the chemicals in the wastewater could enter the water supply and eventually reach humans or damage the environment. One such event occurred in Dimock County, Pennsylvania, where hydraulic fracturing fluid spilled into Stevens Creek resulting in a fish kill (DRN, 2009).


Figure 9: Open wastewater storage pit in Pennsylvania (GWPC, 2009).

To address the risk of potential spills, New York requires that all flowback fluid be contained in closed loop storage containers, which should address the environmental and health risks posed by open pit storage (NYSDEC SGEIS, 2011). Under S6892, all flowback fluid must be recorded at the well head on a hazardous waste manifest (S6892, 2012). This means that exact volumes of waste will be known before it is stored in tanks. Therefore, in the event of an accidental tank discharge, it would be possible to determine how much waste has spilled. Knowing the amounts and chemical compositions of discharged wastewater should also help toxicologists produce risk assessments more accurately and efficiently. Quicker risk assessments could reduce the time between incident and remediation, and limit potential damage to health the environment.

Wastewater that is transported away from the fracturing site is mostly shipped in trucks to authorized disposal sites. S6892 will require that all shipments of fracking fluid be registered and signed for at the point of production and at the point of disposal (S6892, 2012). Although this will not directly prevent accidental spills during transportation, it will ensure that the destination of all chemicals is accounted for, and could decrease the likelihood spills occurring due to the higher safety regulations imposed on the transport of hazardous materials, such as additional training (NYSDEC 2, 2012). Should an accidental discharge occur during transportation, operators will have to take additional actions associated with existing laws on the treatment of hazardous waste (NYSDEC 2, 2012).

Although S6892 does not directly stipulate how or where hydraulic fracturing wastewater must be treated, the hazardous waste definition applied to the waste water does impose certain standards in disposal and treatment. The safety standards for hazardous waste are comparatively higher than for medical waste, the current proposed designation of hydraulic fracturing waste under the Supplementary Generic Environmental Impact Statement (NYSDEC SGEIS, 2011). In New York, hazardous waste can be treated, stored, or disposed of under the guidance of the New York State Department of Environmental Conservation (NYSDEC, 2012). Incineration and oxidation are the two most common ways hazardous waste is treated in New York, while it is mandatory that untreated hazardous be disposed of safely, typically in approved landfills (NYSDEC, 2012).

Figure 10: Flowback fluid storage (Nearing & Brino, 2011)

By requiring that all flowback fluid be tracked and this information made publically available, New York State Senate Bill 6892 ensures greater transparency of the hydraulic fracturing process. The public will be able to access information about the chemicals that flow back to the surface are, the volumes of those chemicals, how they are transported, and where they are transported. Increased transparency would allow the public to become better informed about the risks and benefits associated with hydraulic fracturing, enabling them to make better informed decisions about whether or not to allow fracturing operations in their communities (Finley, 2011). In this way, S6892 helps to solve the problem of the lack of transparency in the hydraulic fracturing process.

The Natural Resource Defense Council argues that forcing companies to disclose the names and volumes of chemicals used to the public will create an incentive for the natural gas industry to use fewer toxic chemicals and more nontoxic chemicals wherever possible (Mall, 2007). If the Natural Resource

Defense Council is correct in their assumptions, then the possibility of toxic contamination would dramatically diminish based on the requirements establish under S6892. This would result in far greater protection of human health and the environment, help to ease public anxiety over the chemicals used in the fracturing process, and possibly help give gas operators the “social license” to operate that the International Energy Agency argues is critical to the global success of the industry (IEA, 2012).

As discussed above, New York Senate Bill 6892 makes significant progress towards solving the environmental and health risks posed by hydraulic fracturing. S6892 defines flowback fluid as hazardous waste, requires that all waste is recorded in manifests from “cradle to grave,” and that this information is made available to the public. S6892 is one of the first bills in the United States to establish a tracking regime for hydraulic fracturing fluids, and is therefore a possible source of inspiration for other state legislation or even national legislation. S6892 also legally recognizes that the chemicals involved in hydraulic fracturing are hazardous, something that has been denied by the natural gas industry (API, 2010). As such, Senate Bill 6892 is an important step in developing a regulatory program that can both protect both human health and the environment while allowing for the development of the Marcellus shale formation and all the economic and energy security benefits associated.

Another significant advantage of New York State Senate Bill 6892 is that it does not create a new regulatory regime. Rather, S6892 gives monitoring and enforcement responsibilities to the New York State Department of Environmental Conservation, which is already responsible for monitoring and tracking hazardous waste from other industries (S6892, 2012). This arrangement should simplify the logistics of developing the tracking program, as well as make it less expensive and faster to implement as existing monitoring and enforcement protocols that can be applied directly to the natural gas industry.

Limitations of Bill 6892

In addition to the advantages to State Senate Bill 6892, there are also several limitations that this report aims to highlight. First, the tracking program could not technically be defined as "cradle to grave". Cradle to grave, if interpreted strictly, would be from when the chemicals are first created until they are permanently disposed. The tracking program created by S6892 tracks the fluids to their disposal, but it defines waste production as when it leaves the well (S6892, 2012). As a result, the chemicals are left unregulated from when they are created, mixed into the fracturing fluid, pumped underground to fracture the shale formation, and while they remain underground for an undetermined amount of time. Thus, there will likely be a significant amount of missing data and chances for undocumented spills before the tracking program has any jurisdiction. It should be recognized that this provision of the bill exists because individual chemicals are produced in multiple states, and therefore fall outside of New York State Department of Environmental Conservation's authority. On the other hand, the regulated flowback fluid is "produced" at the well within New York (Erdman, 2012).

A second limitation of Senate Bill 6892 is the implied assumption that the flowback fluid is well mixed and representative of the original chemicals. However, the original composition of chemicals entering and remaining in the well cannot be adequately determined by only analyzing the flowback fluid (Shafer, Williams, & Mook, 2012). Fracturing fluid is known to mix with natural formation fluid, and absorb minerals from the natural formation rock. The fluid can also be chemically altered by the natural rock formation or adhere to clays in the shale formation (IEA, 2012). Based on this information, it is likely that the chemical composition of the fluid going into the well and that flowing out of the well will be different. Since there is no monitoring or reporting process that begins when the chemicals are first produced to when they emerge from the well as flowback fluid, Senate Bill S6892 does not reduce environmental or health risks, or promote transparency during the entire lifecycle of the chemicals.

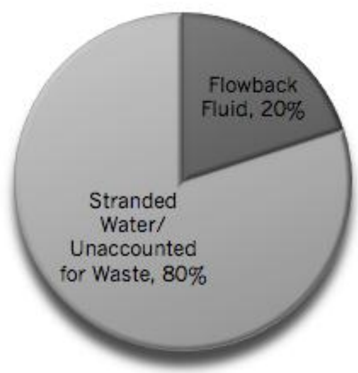


Figure 11: Estimate of waste associated with high- volume hydraulic fracturing (Graphic: Katherine Hoffmaster).

Third, only a fraction of the original fracturing fluid reemerges as flowback fluid and the amount that flows back is not well understood. The New York State Department of Environmental Conservation estimates between 9 and 35% of fracturing fluid comes back to the surface while the IEA estimates 20 to 50% will return to the surface (NYSDEC SGEIS, 2011; IEA, 2012). Therefore, if 3,880,000 gallons of water, sand, and chemicals are used in an average hydraulically fractured well in Marcellus shale, then anywhere from approximately 350,000 to 1,940,000 gallons of the original fluid will return to the surface, and the remaining 1,940,000 to 3,530,000 gallons of fracturing fluid will remain underground as stranded fluid. S6892 makes no mention of hydraulic fracturing fluid that remains trapped underground, nor does it provide any mechanism to ensure that the fracturing fluid remains underground and does not migrate (S6892, 2012). Since the movement of fluids suspended underground is poorly understood this is another potential limitation in S6892's ability to protect the environment and human health.

Fourth, and in connection to the third limitation identified in this report, Senate Bill 6892 only manages fluids produced during "initial" completion of the well (S6892, 2012). Shortly after pressure is released in the fracturing process, the majority of the fracturing fluid that will ultimately return to the surface makes its way upward, but fracturing fluid will continue to emerge for weeks after the well is completed (IEA, 2012). "Initial" flowback is left unclear in the bill, which leaves open the possibility that fracturing fluid will return to the surface after monitoring has stopped. Under the bill's stipulations, this fluid would likely not be classified and managed as hazardous waste. Based on these facts, it can be argued that S6892 does not protect human health or the environment from the equally hazardous fluids that emerge from the well over the course of days and weeks following well completion.

Finally, Senate Bill 6892 stipulates that waste must be tracked from its point of generation at the well through the point of disposal. But the bill does not stipulate where the chemicals should be disposed (S6892, 2012). Thus, the end point, the grave, of hydraulic fracturing waste is left ambiguous in the bill language. New York currently lacks the infrastructure to treat any additional large quantities of hazardous wastewater (Cornell, 2012). This means that there is a possibility that fracturing waste would be transported outside of New York where the Department of Environmental Conservation jurisdiction, and improperly disposed of. This would not solve the risks associated with fracturing fluid; it only moves them. Moreover, even if the waste was treated in New York, S6892 does not create any special stipulations for how it should be treated, or the appropriate level of treatment to mitigate toxicity (S6892, 2012).

Areas Requiring Additional Research

The limitations of Senate Bill 6892 do not mean that the bill is terminally flawed, nor does it imply that the bill fails to make appreciable progress towards creating a regulatory regime that can protect human health and the environment, while also promoting economic and resource development. Rather, these limits in the bill signify that there is still significant room for further research. Amendments could be added or new bills introduced as new knowledge and understanding of the fracturing process emerge. Aside from research that could address the limitations in the bill, there are also other areas that require additional research such as the toxicological effects of the chemicals used in fracturing, and the potential of both hydraulic fracturing and the injection of wastewater in deep wells for disposal to cause earthquakes.

Further research should focus on the fate of the fracturing fluid left underground. The natural gas industries that conduct hydraulic fracturing have argued that, because the shale formations are thousands of feet below drinking water aquifers and are separated by impermeable layers of rock or sediment, any fluids left below ground from fracturing would be unable to contaminate drinking water (Drajem, 2012). However, a study by Duke University in 2012 demonstrated that brine is capable of migrating upwards thousands of feet into groundwater, which implies that wastewater left in shale formations by fracturing could eventually percolate upwards and contaminate drinking water (Lustgarten 2, 2012). Although it was previously thought that this migration would take hundreds to thousands of years, new evidence suggests that fluids injected thousands of feet underground could reach drinking water aquifers in only a few years (Lustgarten 3, 2012). Another study by Duke in April 2011 observed upward migration of methane itself into groundwater (Osborn, Vengosh, Warner, & Jackson, 2011). As more research is conducted on the underground dynamics of hydraulic fracturing, legislation should adapt and grow with this understanding.

Volumes of flowback fluid vary widely as does the period over which these fluids return to the surface. Since the bill limits tracking to only the "initial" flowback fluid, more research should be conducted on the amount of time it takes for flowback fluid to reach the surface and the total volumes that do reach the surface. Once this research is complete, S6892 should be amended or modified so that it covers all fluids returning to the surface and not just the initial fluids that return shortly after completion of the well.

Figure 12: Tricks carrying fracturing fluids (Nearing & Brino, 2011).

We recommend that the New York State Department of Environmental Conservation should further develop the tracking process of chemicals used in hydraulic fracturing from their true conception to when they are used in the fracturing process. This will require improved levels of interstate monitoring beyond the Department's jurisdiction. Because the chemicals move across state lines, they fall under the authority of the federal government. Thus, the Department should find ways around their lack of interstate authority by partnering with neighboring states, or by promoting standardized national legislation.

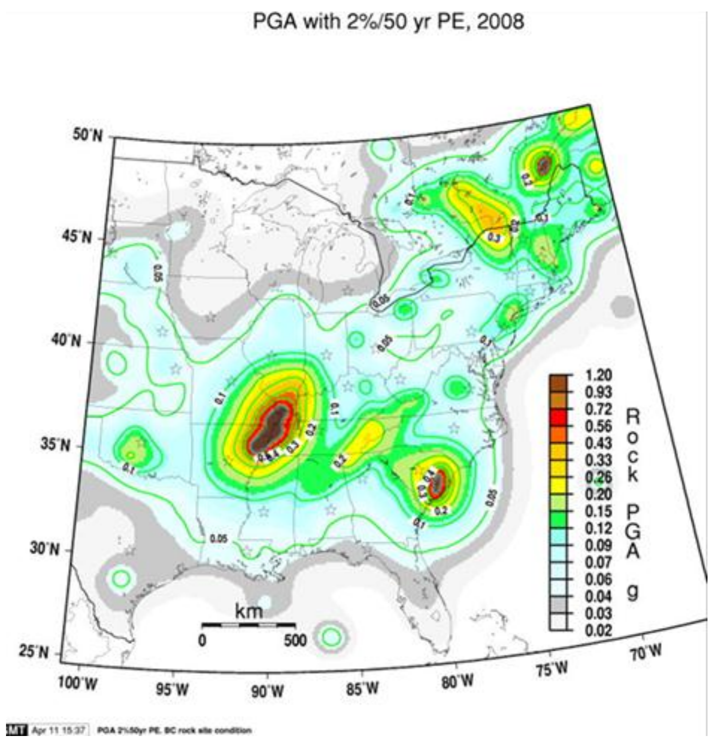


Figure 13: Seismic potential map for the eastern United States measured in potential ground acceleration (PGA) (USGS, 2008).

Expanding the waste tracking program to cover chemicals from their true conception until they are injected into the ground would also help solve the shortcoming of S6892 that assumes flowback fluid is chemically identical to the injected fracturing fluid. Creating a transparent list of chemicals and their volumes before they are injected into the ground would make it easier for further research to be carried out on the underground dynamics of fracturing fluid and how that may affect future legislation.

We also recommend that New York integrate S6892 with legislation in neighboring states to ensure that the waste generated in New York does not merely cross state borders to be disposed of improperly. Research may need to be done to find policy solutions that can solve this shortcoming. Should a regional solution fail to emerge, New York could promote national legislation based on the Interstate Commerce Clause and ensure that hazardous waste produced in New York is disposed of safely in any state it travels to. Further research should also be conducted to identify feasible treatment solutions within New York. Before lifting the moratorium on new drilling permits, the New York State Department of Environmental Conservation should ensure that appropriate infrastructure is developed to treat the large volumes of hazardous waste that will be produced by hydraulic fracturing.

The toxicological effects of the chemicals used in fracturing are another area not optimally addressed in Senate Bill 6892. The toxicological effects of some chemicals that come to the surface with flowback fluid, such as arsenic and benzene, are well understood by the Environmental Protection Agency (EPA IRIS, 2012; EPA IRIS 2, 2012). However, many of the chemicals that are known to be in fracturing fluid are not well understood by the scientific community, and are yet to be adequately tested by the Environmental Protection Agency for their effects on human health or on the environment (EPA RSL, 2012). Consequently more research should be conducted on these chemicals' effects on human health to ensure that communities and policy makers can make optimally informed decisions about drilling.

Another topic that Senate Bill S6892 does not address is the potential of hydraulic fracturing and below ground injection to cause earthquakes, as well as the possible consequences of small earthquakes in New York. According to the International Energy Agency, all fracturing operations cause earthquakes, and these earthquakes are how the natural gas industry's geologists monitor the progress of fracturing (IEA, 2012). Deep injection of fluids has caused documented earthquakes in Ohio and Colorado as early as 1951, but earthquakes caused by injecting hazardous waste underground are less common since the fluids are injected under lower pressure than fracturing (Nicholson & Wesson, 1951). However, these earthquakes are typically too small to be felt by humans on the surface and have so far caused no injuries (Soraghan, 2012; IEA, 2012). Nevertheless, fracturing could pose a more significant risk if done in areas that have high seismic risk potential, such as areas near fault lines (Soraghan, 2012). Therefore, more research is recommended in this field focusing on potential increases in seismic activity associated with hydraulic fracturing and the injection of wastewater in deep wells.

Conclusion

The combination of hydraulic fracturing with horizontal drilling has been a “game changer” for the United States energy industry that has opened up vast reserves of natural gas trapped in shale formations that were previously uneconomical to produce. The economic growth potential, the possibility for energy independence with natural gas, and the comparative environmental advantages of natural gas over oil are all benefits that suggest it is likely that hydraulic fracturing is going to continue in the United States. In New York, the sheer volume of natural gas in the Marcellus shale suggests that the current moratorium on drilling permits will be lifted. When this occurs it is vital that the hydraulic fracturing process is well regulated to ensure both environmental protection and the perseverance of human health. Without assurances that hydraulic fracturing is well regulated and the chemicals used are disposed of safely, the natural gas industry will continue to face strong public opposition. In order to help address concerns about the dangers of fracturing, New York State Senate Bill 6892 creates a waste tracking program to manage flowback fluid as hazardous waste. While this bill is an important step towards developing a regulatory regime that will give the natural gas industry a social license to operate, several shortcomings remain. If the shortcomings in S6892 are fully addressed and further research is conducted to better understand the process of hydraulic fracturing, then New York could join its neighbors in developing the Marcellus shale, but do so in a safer, more transparent way.

Apendix 1: Marcellus Shale's Total Area, Potential, Estimated Return Per Well, and Total Estimated Reserves in Bcf by State.

Assessment Unit/State	Area (square miles)	Well spacing (wells per square mile)	Percent of area untested	Percent of area with potential	EUR (billion cubic feet per well)				TRR (billion cubic feet)
					High	Mid	Low	Average	
Foldbelt	19,063	4	100	5	0.50	0.18	0.03	0.21	757
Maryland	435	4	100	5	0.50	0.18	0.03	0.21	17
Pennsylvania	7,951	4	100	5	0.50	0.18	0.03	0.21	316
Tennessee	353	4	100	5	0.50	0.18	0.03	0.21	14
Virginia	7,492	4	100	5	0.50	0.18	0.03	0.21	298
West Virginia	2,833	4	100	5	0.50	0.18	0.03	0.21	113
Interior	45,161	4	99	37	6.33	1.41	0.06	1.95	137,677
Maryland	763	4	100	37	2.02	0.30	0.02	0.52	629
New York	10,381	4	100	37	7.80	1.79	0.07	2.43	40,124
Ohio	361	4	99	37	2.02	0.30	0.02	0.52	296
Pennsylvania	23,346	4	98	37	7.80	1.79	0.07	2.43	88,182
Virginia	321	4	100	37	2.02	0.30	0.02	0.52	264
West Virginia	9,989	4	99	37	2.02	0.30	0.02	0.52	8,182
Western	39,844	5	100	7	0.35	0.11	0.03	0.13	2,107
Kentucky	207	5	100	7	0.35	0.11	0.03	0.13	11
New York	7,985	5	100	7	0.35	0.11	0.03	0.13	424
Ohio	13,515	5	100	7	0.35	0.11	0.03	0.13	718
Pennsylvania	6,582	5	100	7	0.35	0.11	0.03	0.13	350
Virginia	653	5	100	7	0.35	0.11	0.03	0.13	35
West Virginia	10,901	5	98	7	0.35	0.11	0.03	0.13	569
Total Marcellus	**104,067**	**5**	**99**	**18**	**5.05**	**1.13**	**0.05**	**1.56**	**140,541**

(EIA, 2012)

Appendix 2: Common known chemical additives in fracturing fluid, their purpose, and other common uses.

Exhibit 36: Fracturing Fluid Additives, Main Compounds, and Common Uses.			
Additive Type	**Main Compound(s)**	**Purpose**	**Common Use of Main Compound**
Diluted Acid (15%)	Hydrochloric acid or muriatic acid	Help dissolve minerals and initiate cracks in the rock	Swimming pool chemical and cleaner
Biocide	Glutaraldehyde	Eliminates bacteria in the water that produce corrosive byproducts	Disinfectant; sterilize medical and dental equipment
Breaker	Ammonium persulfate	Allows a delayed break down of the gel polymer chains	Bleaching agent in detergent and hair cosmetics, manufacture of household plastics
Corrosion Inhibitor	N,n-dimethyl formamide	Prevents the corrosion of the pipe	Used in pharmaceuticals, acrylic fibers, plastics
Crosslinker	Borate salts	Maintains fluid viscosity as temperature increases	Laundry detergents, hand soaps, and cosmetics
Friction Reducer	Polyacrylamide	Minimizes friction between the fluid and the pipe	Water treatment, soil conditioner
	Mineral oil		Make-up remover, laxatives, and candy
Gel	Guar gum or hydroxyethyl cellulose	Thickens the water in order to suspend the sand	Cosmetics, toothpaste, sauces, baked goods, ice cream
Iron Control	Citric acid	Prevents precipitation of metal oxides	Food additive, flavoring in food and beverages; Lemon Juice ~7% Citric Acid
KCl	Potassium chloride	Creates a brine carrier fluid	Low sodium table salt substitute
Oxygen Scavenger	Ammonium bisulfite	Removes oxygen from the water to protect the pipe from corrosion	Cosmetics, food and beverage processing, water treatment
pH Adjusting Agent	Sodium or potassium carbonate	Maintains the effectiveness of other components, such as crosslinkers	Washing soda, detergents, soap, water softener, glass and ceramics
Proppant	Silica, quartz sand	Allows the fractures to remain open so the gas can escape	Drinking water filtration, play sand, concrete, brick mortar
Scale Inhibitor	Ethylene glycol	Prevents scale deposits in the pipe	Automotive antifreeze, household cleansers, and de-icing agent
Surfactant	Isopropanol	Used to increase the viscosity of the fracture fluid	Glass cleaner, antiperspirant, and hair color
Note: The specific compounds used in a given fracturing operation will vary depending on company preference, source water quality and site-specific characteristics of the target formation. The compounds shown above are representative of the major compounds used in hydraulic fracturing of gas shales.			

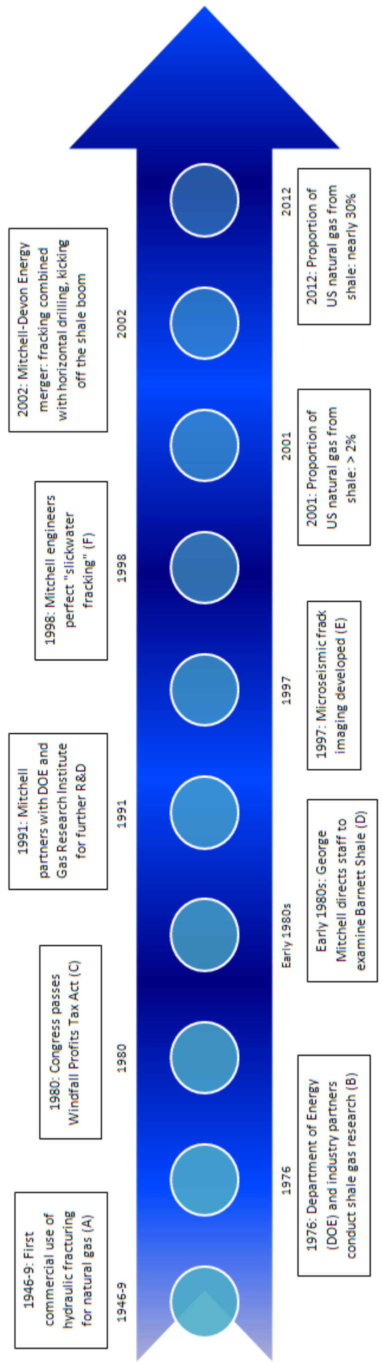
(GWPC, 2009)

Appendix 3:Definitions in S6892.

1. **Flowback fluid** is defined as; “the liquids produced during initial completion and clean-up of the well or clean-up of a well following re-fracture or work over of a well”.
2. **Generators** is defined as “Any owner or operator of an oil or gas well pad whose acts or processes produce solid or liquid waste”.
3. **High Volume Hydraulic Fracturing** is defined as “Hydraulic Fracturing for natural gas extraction using greater than 300,000 gallons of water regardless of whether the well is vertical, directional or horizontal”.
4. **Manifest** is defined as “the form used for identifying the quantity, composition, and the origin, routing and destination of liquid and solid waste during its transportation from the point of generation to any intermediate points and finally to the point of ultimate disposal”.
5. **Oil and Gas production** is defined as “all activities associated with the exploration and production of oil and gas, including, but not limited to, (a) Development of oil and gas wells; (b) Activities associated with drilling, stimulating, completing, or operating an oil or gas well (c) Activities associated with the construction or operation of facilities for the collection and transmission of oil and gas from wells to consumers; and (d) the transportation of materials associated with an oil and gas well site or production whether or not the oil or gas is re-injected into the subsurface of the earth, from a geological formation and the transportation of that oil or gas to another location”.
6. **Production Brine** is defined as as "Liquids co-produced during oil and gas production”.
7. **Solid and Liquid waste** are defined as, but not limited to, “production brine, produced water, flowback fluid, and drill cuttings from oil and gas production”.
8. **Transport** is defined as “the movement of liquid and solid waste associated with oil and gas production from the point of generation to any intermediate points and finally to the point of ultimate disposal. For the purposes of this title, the point of generation with regard to facilities that are generators of such waste shall be the point at which such waste leaves the generators facility site”.

(S6892, 2012)

Appendix 4: Timeline of History of Hydraulic Fracturing



Notes:

A. There is no consensus among sources as to the precise year.
B. In which massive hydraulic fracturing (MHF) techniques were developed.
C. This incentivized unconventional gas development.
D. Conventional natural gas wells in North Texas were nearing exhaustion.
E. This involved collaboration among DOE, Sandia Labs and Mitchell Energy.
F. This involved the devising the optimal combination of fluid components and was developed from prior work done by engineers at Union Pacific Resources.

Graphic: Daniel Robicheaux

Works Cited

ANGA. (2012). *Hydraulic Fracturing 101*. Retrieved August 02, 2012, from American Natural Gas Alliance: http://anga.us/media/41084/hydraulic%20fracturing%20101.pdf

API. (2010). *Freeing Up Energy: Hydraulic Fracturing: Unlocking America's Natural Gas Resources.* Washington D.C.: American Petroleum Institute.

Bishop, R. (1999, September). *Naturally Occurring Radioactive Materials (NORM) in Produced Water and Oil-Field Equipment---An Issue for the Energy Industry.* Retrieved June 9, 2012, from US Geological Survey Fact Sheet .

BP 2. (2012). *BP Statistical Review of World Energy: June 2012.* London: BP.

BP. (2012). *BP Energy Outlook 2030.* London: BP.

Chesapeak. (2012). *Hydraulic Fracturing Fluid Makeup*. Retrieved July 24, 2012, from Chesapeak Energy: http://www.chk.com/Environment/Drilling-and-Production/Pages/Hydraulic-Fracturing-Fluid.aspx

Colborn Theo, F. V. (1993). Developmental Effects of Endocrine-Disrupting Chemicals in Wildlife and Humans. *Environmental Health Perspectives*, 378-384.

Considine, T., Watson, R., & Blumsack, S. (2010). *The Economic Impacts of the Pennsylvania Marcellus Shale Natural Gas Play: An Update.* University Park, PA: The Pennsylvania State University College of Earth and Mineral Sciences Department of Energy and Mineral Engineering.

Cornell. (2012, March 21). *Gas Wells: Waste Management of Cuttings, Drilling Fluids, Hydrofrack Water and Produced Water*. Retrieved 08 05, 2012, from Cornell: http://wri.eas.cornell.edu/gas_wells_waste.html

Drajem, M. (2012, July 10). Pennsylvania Fracking Can Put Water at Risk, Duke Study Finds. *Bloomberg Business Week*.

DRN. (2009). *NATURAL GAS WELL DRILLING AND PRODUCTION In the Upper Delaware River Watershed Fact Sheet.* Bristol: Delaware Riverkeeper Network.

EIA 2. (2011, August 30). *Today In Energy*. Retrieved August 02, 2012, from Pennsylvania Drives Northeast Natural Gas Production Growth: http://www.eia.gov/todayinenergy/detail.cfm?id=2870

EIA 2. (2012, July 09). *Energy In Brief*. Retrieved August 02, 2012, from What is Shale Gas and Why is it Important: http://www.eia.gov/energy_in_brief/about_shale_gas.cfm

EIA. (2010). *Updated Capital Cost Estimates for Electricity.* Washington D.C.: U.S. Energy Information Administration.

EIA. (2011). *Review of Emerging Resources: U.S. Shale Gas and Shale Oil Plays.* Washington D.C.: U.S. Department of Energy.

EIA. (2012). *Annual Energy Outlook 2012: With Projections to 2035.* Washington D.C.: U.S. Energy Information Administration.

EIA 3. (2012, July 23). *Today in Energy.* Retrieved August 02, 2012, from Spot Natural Gas Prices at Marcellus Trading Point Reflect Pipeline Constrains: http://www.eia.gov/todayinenergy/detail.cfm?id=7210

EIA NY. (2012, July 31). *New York Dry Natural Gas Production*. Retrieved August 4, 2012, from Energy Information Administration: http://www.eia.gov/dnav/ng/hist/na1160_sny_2m.htm

EIA Penn. (2012, July 31). *Pennsylvania Natural Gas Production*. Retrieved 08 04, 2012, from Energy Information Adminsitration: http://www.eia.gov/dnav/ng/hist/na1160_spa_2m.htm

Endo, T. T. (2006). Effects of Glutaraldehyde Exposure on Human Health. *Journal of Occupational Health, Vol. 48*, pp. 75-87.

EPA 2. (2012, July 04). *EPA's Study of Hydraulic Fracturing and Its Potential Impact on Drinking Water Resources*. Retrieved August 01, 2012, from U.S. Environmental Protection Agency: http://www.epa.gov/hfstudy/

EPA. (2002). *Exemption of Oil and Gas Exploration and Production Wastes from Federal Hazardous Waste Regulations.* Washington D.C.: U.S. Environmental Protection Agency.

EPA. (2011). *Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources.* Washington D.C.: U.S. Environmental Protection Agency.

EPA. (2012). *Basic Information about the Aresenic Rule*. Retrieved June 13, 2012, from United States Environmental Protection Agency: http://water.epa.gov/lawsregs/rulesregs/sdwa/arsenic/Basic-Information.cfm#one

EPA 3. (2012, March 6). *Radiation Protection*. Retrieved June 10, 2012, from United States Environmental Protection Agency: http://www.epa.gov/rpdweb00/radionuclides/radium.html#affecthealth

EPA IRIS 2. (2012, July 31). *Benzene (CASRN 71-43-2).* Retrieved August 05, 2012, from U.S. Environmental Protection Agency: http://www.epa.gov/iris/subst/0276.htm

EPA IRIS. (2012, July 31). *Arsenic, inorganic (CASRN 7440-38-2).* Retrieved August 06, 2012, from U.S. Environmental Protection Agency: http://www.epa.gov/iris/subst/0278.htm

EPA IRIS. (2012, July 31). *Glycidaldehyde (CASRN 765-34-4)* . Retrieved August 05, 2012, from U.S. Environmental Protection Agency: http://www.epa.gov/iris/subst/0315.htm

EPA RSL. (2012, May). *Regional Screening Level (RSL) Summary Table April 2012.* Retrieved July 30, 2012, from U.S. Environmental Protection Agency: http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/Generic_Tables/pdf/master_sl_table_run_MAY2012.pdf

Erdman, J. (2012, August 07). Legislative Director to Senator Mark Grisanti. (C. V. converstation), Interviewer)

Finkel, M. L., & Law, A. (2010). The Rush to Drill for Natural Gas: A Public Health Cautionary Tale. *American Journal of Public Health, Vol. 101*, 784-785.

Finley, B. (2011, October 11). EPA to set Standards for Disposal of Fracking Wastewater in Treatment Plants. *Denver Post*.

FracFocus. (2012). *What Chemicals Are Used?* Retrieved July 12, 2012, from FracFocus: http://fracfocus.org/chemical-use/what-chemicals-are-used

Geny, F. (2010). *Can Unconventional Gas be a Game Changer in European Gas Markets?* Oxford: The Oxford Institute for Energy Studies.

Goldstein, D. (2004). *Out of Gas: The End of the Age of Oil.* New York: W. W. Norton & Company.

GWPC. (2009). *Modern Shale Gas Development in the United States: A Primer.* Oaklahoma City: Ground Water Protection Council.

IEA. (2010). *Medium-term Oil and Gas Markets 2010.* Paris: International Energy Agency.

IEA. (2011). *World Energy Outlook 2011 Special Report: Are we Entering a Golden Age of Gas?* Paris: International Energy Agency.

IEA. (2012). *World Energy Outlook 2012 Special Report on Unconventional Gas: Golden Rules for a Golden Age of Gas.* Paris: Energy Information Agency.

Klopott, F., & Efstathiou, J. (2012, June 13). Cuomo Said to Want to Want to Limit Fracking to 5 New York Counties. *Bloomberg*.

L. Larissa, A. S. (2004). Chronic Toxicity of Glutaraldehyde: Differential Sensitivity of Three Freshwater Organisms. *Aquatic Toxicology Vol. 71*, 283-296.

Lenntech. (2011). *Water Treatment Solutions*. Retrieved June 14, 2012, from Lenntech: http://www.lenntech.com/water-ecology-faq.htm

Lustgarten 1, A. (2009, November 9). *Natural Gas Drilling Produces Radioactive Wastewater*. Retrieved June 13, 2012, from Scientific American: http://www.scientificamerican.com/article.cfm?id=marcellus-shale-natural-gas-drilling-radioactive-wastewater

Lustgarten 2, A. (2012, July 9). New Study: Fluids From Marcellus Shale Likely Seeping Into PA Drinking Water. *ProPublica*.

Lustgarten 3, A. (2012, May 1). New Study Predicts Frack Fluids Can Migrate to Aquifers Within Years. *ProPublica*.

Mall, A. (2007). *Drilling Down: Protecting Western Communities from the Health and Environmental Effects of Oil and Gas Production.* New York: Natural Resources Defense Council.

Mellquist, N. (2011). *Natural Gas and Renewables: The Coal to Gas and Renewables Switch is On!* DB Climate Change Advisors. New York: Deutche Bank Group.

MSDS 2. (2010, November 1). *Material Safetly Data Sheet: Benzene MSDS*. Retrieved July 12, 2012, from Science Lab: http://www.sciencelab.com/msds.php?msdsId=9927339

MSDS. (2012, November 1). *Material Safetly Data Sheet: Glutaraldehyde Solution, 50% MSDS*. Retrieved July 13, 2012, from Science Lab: http://www.sciencelab.com/msds.php?msdsId=9924161

Nearing, B., & Brino, A. (2011, November 07). *Cutting waste in gas drilling*. Retrieved August 12, 2012, from Timesunion.com: http://www.timesunion.com/local/article/Cutting-waste-in-gas-drilling-2254667.php

Nicholson, C., & Wesson, R. (1951). *Earthquake Hazard Associated With Deep Well Injection - A Report to the U.S. Environmental Protection Agency*. Denver: U.S. Geological Survey.

NPI. (1992). *Benzene: Environmental Effects*. Retrieved June 9, 2012, from National Pollutant Inventory: http://www.npi.gov.au/substances/benzene/environmental.html

NYSDEC 2. (2011, September 7). *The Environmental Review Process for Natural Gas Exploration in the Marcellus Shale*. Retrieved June 10, 2012, from New York State Department of Environmental Conservation: http://www.dec.ny.gov/energy/46288.html

NYSDEC 2. (2012). *Hazardous Waste Manifest System*. Retrieved July 28, 2012, from New York State Department of Environmental Conservation: http://www.dec.ny.gov/chemical/8793.html

NYSDEC. (2011, September 7). *Marcellus shale.* Retrieved July 20, 2012, from NYS Department of Environmental Conservation.: http://www.dec.ny.gov/energy/46288.html

NYSDEC. (2012). *Hazardous Waste Management Facilities*. Retrieved August 11, 2012, from New York State Department of Environmental Conservation: http://www.dec.ny.gov/chemical/8768.html

NYSDEC SGEIS. (2011). *Supplemental Generic Environmental Impact Statement On The Oil, Gas and Solution Mining Regulatory Program.* Albany: New York State Department of Environmental Conservation.

OECD. (2011). *Shale Gas Outlook for the U.S.: Natural Gas Markets and Global Gas Resources.* Paris: Organization for Economic Cooperation and Development.

OPEC. (2011). *World Oil Outlook 2011.* Vienna: Organization of Petroleum Exporting Counties.

Osborn, S., Vengosh, A., Warner, N., & Jackson, R. (2011 йил 14-April). *Methan Contamination of Drinking Water Accompanying Gas-Well Drilling and Hydraulic Fracturing.* Retrieved 2012 йил 8-August from ProPublica: http://www.propublica.org/documents/item/methane-contamination-of-drinking-water-accompanying-gas-well-drilling

PADEP. (2012, August 02). *PA DEP Oil & Gas Reporting Website - Welcome*. Retrieved August 05, 2012, from Pennsylvania Department of Environmental Protection: https://www.paoilandgasreporting.state.pa.us/publicreports/Modules/Welcome/Welcome.aspx

Pearce, F. (2006). *When the Rivers Run Dry: Water - The Defining Crisis of the Twenty-first Century.* Boston: Beacon Press.

Pless, J. (2012). *Natural gas development and hydraulic fracturing a policymaker's guide.* Washington D.C.: National Conference of State Legislatures.

Rahm, B. G., & Riha, S. J. (2 0 1 2). Toward Strategic Management of Shale Gas Development: Regional, Collective Impacts on Water Resources. *e n v i r o n m e n t a l s c i e n c e & p o l i c y Vol. 1 7*, 1 2 – 2 3.

Range Resources. (2011). *Inflection Point.* Pittsburgh: Range Resoucres Corporation.

S6892. (2012). *NY Senate Bill S6892: High-volume Hydraulic Fracturing Waste Tracking Program.* Albany: New York Senate.

Schneider, K. (2011). Double Choke Point: Demand for Energy Tests Water Supply and Economic Stability in China and the U.S. *Circle of Blue*.

Shafer, M., Williams, J., & Mook, W. (2012). *Hydraulic Fracturing in New York State.* Canton: Biology Department St. Lawrence University.

Siegel, J. (2012, April 7). *The World's Largest LNG Supplier?* Retrieved August 03, 2012, from Barron's: Other Voices: http://online.barrons.com/article/SB50001424052748704759704577267370939083182.html

Soraghan, M. (2012, March 29). *EARTHQUAKES: 'Remarkable' Spate of Man-made Quakes Linked to Drilling, USGS Team Says*. Retrieved August 06, 2012, from E&E Publishing: http://eenews.net/public/energywire/2012/03/29/1

Steingraber, S. (2011). *The Potential Health Impacts of Hydraulic Fracturing Wastewater and Drill Cuttings.* Canandaigua: New York State Senate Standing Committee on Environmental Conservation.

Steward, D. (2011, December 20). Interview with Dan Steward, Former Mitchell Energy Vice President. (Breakthrough.org, Interviewer)

Studiosayers. (2011, April 12). *Studio Sayers Entries in Infographics*. Retrieved August 11, 2012, from Studio Sayers: http://www.studiosayers.com/blog/tag/infographics

Tertzakian, P. (2006). *A Thousand Barrels a Second: The Coming Oil Break Point and the* . New York: McGraw-Hill.

University of Texas. (2012). Fact-Based Regulation for Environmental Protection in Shale Gas Development. *University of Texas*, 59.

USGS. (2008). *PGA with 2%/50 yr PE, 2008*. Retrieved August 05, 2012, from United States Geological Survey: http://earthquake.usgs.gov/hazards/products/conterminous/2008/maps/ceus/ceus.2pc50.pga.jpg

Veil, J. (2010). *Water Management Technologies Used by Marcellus Shale Gas Producers.* Washington D.C.: United States Department of Energy.

WEC. (2012). *Survey of Energy Resources: Shale Gas - What's New.* London: World Energy Council.

Wright, S. (2012, July 14). An Unconventional Bonanza. *The Economist*.

YSI Environmental. (2011). *Network Monitors Water Quality in Shale Gas.* Yellow Springs: YSI Environmental.

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