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# To Frack or Not To Frack

## A Report on the Implications of Hydraulic Fracturing Operations

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# Abstract

Ongoing discussion about hydraulic fracturing has shown multiple views towards the values of hydraulic fracturing in modern society. These views question whether or not the possible future economic benefits and independence of energy outweigh the potential environmental risks and the public's safety. In order to provide insight upon the subject, research was conducted about the overall procedure of hydraulic fracturing, the economic benefits and the environmental impacts. Furthermore, the laws that regulate hydraulic fracturing were assessed, along with the concerns of the public, and the alternative methods for hydraulic fracturing. With the accumulated research from these topics, it was concluded that with proper regulation, the economic benefits outweigh the environmental risks with regards to hydraulic fracturing.

# Acknowledgement

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## Background

The origin of hydraulic fracturing can be traced back to the 1860s. Nitroglycerin was used to for oil well stimulation.[1] It was used to break-up shallow oil-bearing formation in many states of the US in order to increase oil recovery. This is the principle on which hydraulic fracturing was founded.

In the 1930s, the oil industry started exploring the idea of using acid injection into the ground for well stimulation.[2] It was observed that this method created fractures that would not close.[2] These fractures acted as flow channels, which increased productivity.

Although preliminary results of using fluid injection for well stimulation were positive, it was not until an in-depth study by Floyd Farris that the relationship between well performance and treatment pressures that formation fractures during fluid injection became better understood.[2] As a result of this study, Farris conceived the idea of hydraulically fracturing oil-bearing formations in order to increase oil and gas production in wells.

In 1949, Halliburton Oil Well Cementing Company was given exclusive license to perform hydraulic fracturing. Halliburton performed the first two commercial hydraulic fracturing treatments in Oklahoma and Texas.[2][3] In the first year, more than 300 hydraulic fracturing treatments were performed.[3] The average increase of well productivity in that year was 75%.[3]

In the first few years, there was much advancement in hydraulic fracturing. The industry moved away from using gelled crude oil as fracturing fluid to kerosene. In the latter part of 1952, refined and crude oil became the fluid of choice for fracturing due to their relatively cheaper price and lower viscosities, which exhibits less friction.[2] In 1953, an advancement in the field allowed water to be used as a fracturing fluid.[2] However, in order for water to be used effectively as fracturing fluid, gelling agents needed to be developed for purposes such as minimizing emulsion with the formation fluid and effect on water-sensitive formation.[2] Over the years, many additives were developed to enhance the water-based fracturing fluid. The modern fracturing fluid is commonly a solution of brines, water and acid.

Proppants used in hydraulic fracturing have remained relatively unchanged. Most hydraulic fracturing treatments still used sand as proppants. However, the lower viscosities of fracturing fluids and more powerful pumps have allowed for higher concentrations of proppants in the fluids.

In its infancy, hydraulic fracturing treatments of oil wells were performed using a few treatments now use approximately 60,000 gallons of fluid.[2] Large-scale treatments can use as much as 8 million gallons of fluid.[3]

*Figure 1 - Example of Hydraulic Fracturing Site in Michigan*[77]

Modern hydraulic fracturing results are no longer random. Scientists and engineers now use advanced finite-element software to study and predict fracture geometries and flow properties in three dimensions [2].

## Oil and Gas Exploration and Production Process Overview

Oil and gas exploration and production is a long and complex process. The entire process, from the start to finish, can take many years to complete. The process can be broken down into the following stages [4]:

1. Due diligence – Oil companies carry out assessments of potential health, safety, social, political and environmental impacts
2. Prequalification – Necessary documents must be submitted to authorities in order to receive an exploration license.
3. Seismic exploration – seismic surveys are carried out to identify the subsurface geological structures and the likelihood of hydrocarbons being present.
4. Site survey – surveys are carried out to acquire more details about the area where a well may be drilled.
5. Exploration drilling – wells are drilled in order to more accurately determine the presence of oil or gas in the subsurface formation.
6. Appraisal drilling – if data acquired from exploration drilling is promising, appraisal wells are drilled to assess characteristics of the proven hydrocarbon reservoir.
7. Development – If appraisal wells demonstrate technically and commercially viable quantities of hydrocarbons, production wells are drilled and well completions such as perforation and hydraulic fracturing are carried out.

8. Production – the well is finally ready for production.
9. Decommission – the well is sealed and the well site undergoes reclamation process.

   The entire process can take anywhere between 10-30 years. Most of the time is spent on obtaining the necessary licenses and well development and production.

## Reason for Hydraulic Fracturing

Hydrocarbons exist in underground formations. Sometimes these vast reserves of oil and gas are trapped in low-porosity, low-permeability shale and other rock formations. These tight formations make it highly uneconomical for oil wells to go into production. In the United States, tight gas (gas in tight shale) is defined as gas in shale with less than 10% porosity and 0.1 millidarcy permeability.[5]

Hydraulic fracturing allows fissures to be created in the formation that holds the hydrocarbons. This creates pathways for the trapped hydrocarbons to flow from the formation and into the production tubing of the well. Without hydraulic fracturing, the United States net natural gas imports would be significantly higher than the current amount.[6]

## The Process

After the well has been perforated and stimulation by hydraulic fracturing is deemed necessary, aqueous solution consisting of water, chemicals and proppants are injected into the well at high pressure. The fracturing solution is injected at a pressure greater than the pressure of the formation. The solution then fills the newly created fissures in the shale and rock formation. Once the predetermined parameter of the hydraulic fracturing treatment has been reached (i.e. pressure and duration of treatment), the fluid is circulated back to the surface, leaving proppants in the fissures. The proppants, which are solids, prevent the fissures from closing.

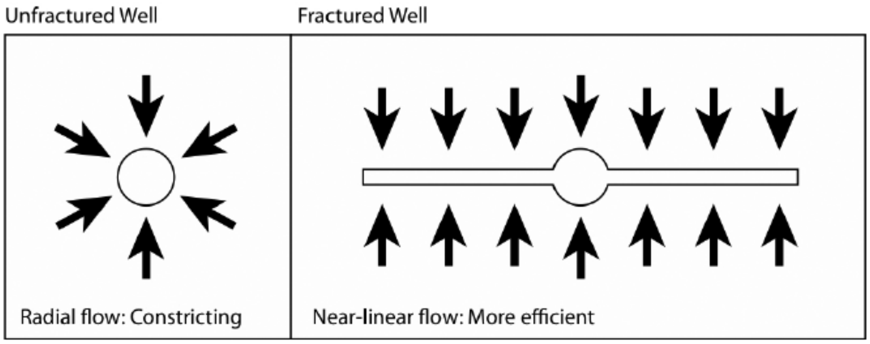


*Figure 2 - Mechanics of production increase by hydraulic fracturing*[76]

The treatment pressure and injection rate is determined before arriving to the work site. The wellhead pressure can be calculated using the following equation:

$$P_{wellhead} = P_{bottomhole} + P_{pipe} + P_{perforation} + P_{fluid}$$

Where $P_{bottomhole}$ is the actual fracturing pressure at the bottom of the well, $P_{pipe}$ is the pressure due to the friction cause by the well casing, $P_{perforation}$ is the pressure drop across perforated zones in the casing, $P_{fluid}$ is the hydrostatic pressure of the fluid. $P_{bottomhole}$ is the pressure at which the rock can be fractured.[7] It is calculated using the fracture gradient of the formation, depth and the excess pressure, which is the pressure required to extends the fractures further into the oil-bearing formation. Figure 2 shows the mechanics of hydraulic fracturing.

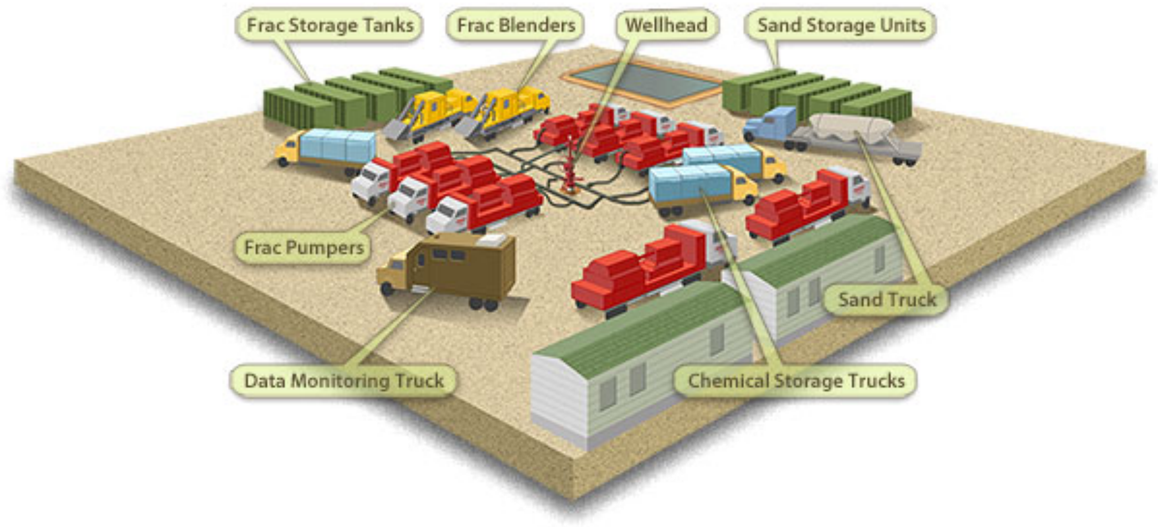


*Figure 3 - Equipment required to perform hydraulic fracturing operations*[69]

After preliminary calculations are completed, the site is set up for treatment. Due to the specialized and scale of modern day hydraulic fracturing operations, bespoke equipment such as pumping units and storage tanks are required. Figure 3 shows the basic equipment needed for hydraulic fracturing operations. Hydraulic fracturing operations typically consists of:

- Storage for fluid (mostly water), chemical additives and proppants.
- A specialized blender to combine chemicals additives, base fluid and proppants in specific concentrations according to preliminary calculations.
- Fracturing pumpers are required. The exact number depends on the treatment pressure required to fracture the well.
- Transport trucks to transport all the materials and equipment.
- Components that connect the pumps, storage units and wellhead together.

- A van/truck equipped with computers to monitor, control and record data of the treatment.

Hydraulic fracturing can be broken down into three main stages:

1. Pad – Fracturing treatment is initiated. Fluid is pumped into the targeted formation at high pressure. At this stage, fractures are created and propagate into the formation. Typically, this stage is performed without any proppant. However, in some special cases, it may be necessary to mix in small amount of sand. Taking into account fluid leak-off into the formations, the pad process pumps enough fluid into the well to complete the entire hydraulic fracturing process.
2. Proppant Stage – The second stage of the treatment is pumping proppants into the formation. Depending on the formations and other parameters, the concentrations of proppant vary from one operation to another. Most common proppant used in hydraulic fracturing is ordinary sand. Fracturing companies employ the use of large sieves in order to ensure that the sand used in this process meets the size specification. Other specialized proppants are also used in some cases.
3. Displacement/Flush - After the proppant stages, there may be sand left in the pipe. To get rid of the sand, the well is flushed with more fluid in order to move the proppants into the formation. The fluid used in this stage is typically water without any additives. The same fluid that was used in the previous stages may also be used.

In wells with multiple production zones, hydraulic fracturing treatments may be done in multiple stages, starting from bottom to the top, in order to better control and monitor the process.[8]

## Fluids and Proppants

Hydraulic fracturing fluids contain many chemical additives and proppants. Each treatment requires specific chemical additives to be used in specific concentration. Approximately 99% of the hydraulic fracturing fluid is water.[9] The chemicals used in hydraulic fracturing treatments can be categorized into the following categories[10]:

1. Acid – acid dissolves minerals and help initiate crack propagation in the rock formation. The reactions between the acid and the rock formation create salts, water and carbon dioxide.
2. Biocide – biocide eliminates any microorganisms in the water that can potentially cause corrosive byproducts.
3. Breaker – inside the formation, breakers react with crosslinkers and gel to enable fluid to easily flow to the borehole. This reaction produces ammonia and sulfate salts. These byproducts are returned in produced water.
4. Clay Stabilizer – Clay stabilizers react with clays in the formation in order to keep the shale structure intact. The byproduct of this reaction is sodium chloride.
5. Corrosion Inhibitor – Corrosion inhibitors protect the production casing from corrosion by forming bonds to metal surfaces.
6. Crosslinker – maintains viscosity as temperature increases by combining with breakers in the formation. This process creates salts.
7. Friction Reducer – the friction reducer decreases the friction between the base water and the pipe. Only a small amount returns with the produced water. The rest remains in the formation and is broken down by exposure to temperature and breaker.

8. Gelling Agent – gel thickens the fluid in order to suspend proppants.
9. Iron Control – this chemical prevents precipitation of metal oxides.
10. Non-Emulsifier – non-emulsifier separate oil/water mixtures.
11. pH Adjusting Agent – this chemical reacts with the acid agents in the treatment fluid in order to maintain neutral pH so that all the other chemicals function properly.
12. Scale Inhibitor – this chemical prevents scale formation in pipes. The majority of the by-products from the chemical reaction are returned with the produced water while the microorganisms in the formation break down the remaining.
13. Surfactant – reduces surface tension of the treatment fluid. This improves fluid recovery from the well after the treatment is complete.

## Well Classifications

The Environmental Protection Agency's (EPA) Underground Injection Control Program (UIC) defines an injection well as "a bored, drilled, or driven shaft, or a dug hole that is deeper than it is wide, or an improved sinkhole, or a subsurface fluid distribution system". There are 5 classes of injection wells.[11]

**Class I** (Figure 4) – injection wells for hazardous and non-hazardous wastes. These wastes are injected deep into isolated rock formations, usually thousands of feet below that lowermost underground sources of drinking water (USDW) as defined by the EPA. Class I wells are mainly used by the petroleum refining, commercial disposal, municipal wastewater treatment, chemical, metal, pharmaceutical and food production. Class I hazardous injection wells have some of the most stringent regulations.[11]

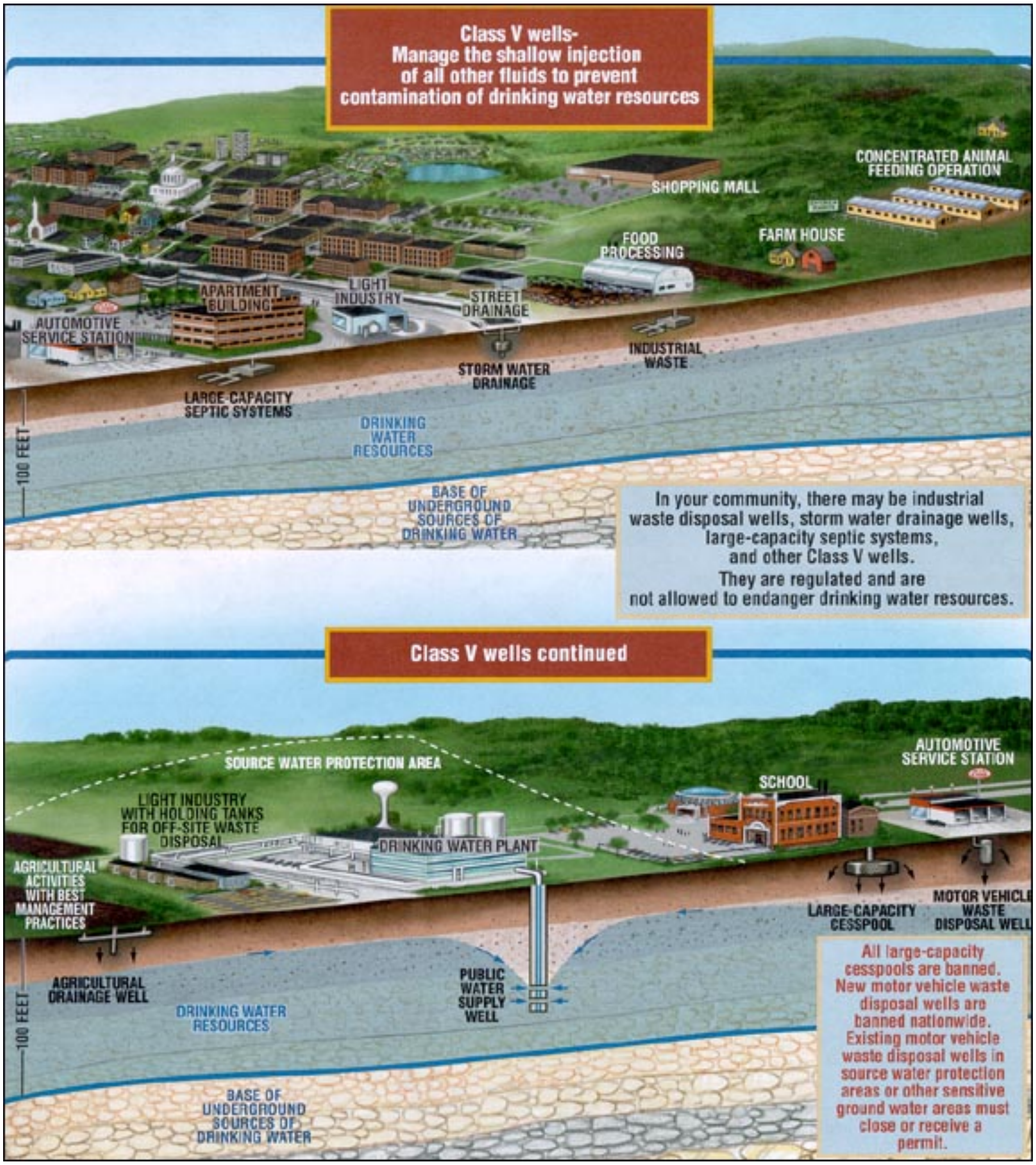
**Class II** (Figure 4) – injection wells associated with oil and natural gas production. There are three types of Class II injection wells; enhanced recovery wells, disposal wells and hydrocarbon storage wells. Enhanced recovery wells inject fluids into the formation in order to increase the amount of recoverable oil and natural gas. Disposal wells are wells where the brine and water used during the oil and natural gas recovery process are separated and injected back into the formations. Hydrocarbon storage wells are injection wells in which hydrocarbons are injected into underground formations for the purpose of storage as part of the U.S. Strategic Petroleum Reserve.[11]

**Class III** (Figure 4)– Injection wells used to mine uranium, salt, copper and sulfur. In order to prevent contamination of water aquifers, more fluid is extracted than is injected in order to prevent harmful fluids from migrating through underground formations.[11]

**Class IV** – Injection wells used only as part of an EPA- or state-authorized ground water cleanup action. These wells are shallow wells used to inject hazardous waste into or above a formation that contains a USDW.[11]

**Class V** (Figure 5) – injection wells similar to Class IV wells but can only be used to inject non-hazardous fluids underground.[11]

*Figure 4 - Class I, II, and III Injection Wells[70]*



Class V wells-
Manage the shallow injection
of all other fluids to prevent
contamination of drinking water resources

In your community, there may be industrial waste disposal wells, storm water drainage wells, large-capacity septic systems, and other Class V wells.
They are regulated and are not allowed to endanger drinking water resources.

Class V wells continued

All large-capacity cesspools are banned. New motor vehicle waste disposal wells are banned nationwide. Existing motor vehicle waste disposal wells in source water protection areas or other sensitive ground water areas must close or receive a permit.

*Figure 5 - Class V Injection Well[70]*

## Effects of Hydraulic Fracturing

Hydraulic fracturing has been proven to increase oil and natural gas recovery. Since its conception, this method has been the primary well stimulation technique in the United States. It has helped United States, one of the world's biggest consumers of natural gas, decrease its dependency on natural gas import and create a more stable and secure economy though the growth of tax revenues and the establishment of numerous jobs. However, there are few concerns regarding the impacts of hydraulic fracturing. These concerns consist mainly of potential health and environmental effects. Most common environmental impacts include groundwater contamination, soil and air pollution, and fracturing-induced earthquakes. These issues are mainly being associated with the methods and chemicals used during the fracturing process. Furthermore, controversial research have found that the chemicals used in the fracturing fluid could affect sensory organs, as well as respiratory, gastrointestinal, nervous, immune, cardiovascular, and endocrine systems.[11]

## Economic Benefits

United States territories contain major reserves of natural gas trapped in dense rock formations that are sufficient to supply the country for more than 100 years according to studies published by the American Petroleum Institute [6]. They are largely found in the East Coast in units of marine sedimentary rock such as Marcellus shale. As the formation of this shale is very dense and hardly penetrable, hydraulic fracturing is required to unlock these resources. This process in combination with new technology such as advance instruments to allow horizontal drilling is considered a technological breakthrough in the oil and gas industry. The global economic turndown of the 21st century had its toll on United States economy as well. The collapse of many financial institutions dating from 2007 to 2009, let alone big financial corporations, affected severely oil and gas prices, employment rates, federal debt and much more. Although this recession was declared ceased, its aftereffects are still to a certain extent visible up to this day. The implementation of hydraulic fracturing technology promises valuable economic growth and can be a key factor in helping the community with greater employment opportunities and improved national economic security.

### Economic growth due to Employment

Since the first successful hydraulic fracturing application in the mid years of the last century, the positive effects of such application in the economic sphere of the United States have become even more visible. The 35 states that currently hold shale gas have the potential to increase the number of employment opportunities within the producing states, non-producing ones, and subsequently upsurge tax revenue.

The job market has widened noticeably as hydraulic fracturing application has expanded over the years and it further anticipates an even more cost-effective future. The producing states, the ones that are experiencing the most hydraulic fracturing job boom, are providing a variety of job opportunities starting from positions directly related to the industry such as engineers, technicians, machinery operators, and field supervisors, to office positions such as clerks, office managers, accountants, and financiers. Although the employees whose duties are directly related to the fracturing industry have to be on or near the site, other positions are offered ad can be occupied out of the producing states. In late September of 2014, a new study conducted by IHS Cambridge Energy Research Associates (IHS CERA), was able to relate the growth of employment to the unconventional oil and gas production. This study showed that the supply chain industries, responsible for gas extraction from tight shales, created a total of 524,000 jobs in 2012 and it expects to reach 757,000 jobs in 2025, an increase of 45 percent in producing states [11]. Non-producing states are also expected to be affected by job creations due to supply chain activity. In 2012, 460,000 jobs were related to the construction and support contribution of the non-producing states. A potential of 630,000 jobs in 2025 are expected for creation [12].

The data shown in Appendix II is extracted from the Bureau of Labor databases. It indicates employment demographics for positions related to the oil and gas extraction industry during 2012, the projections for 2022, as well as the employment change during this time frame. As seen, although a few occupations are not projected to experience major changes over the next decade due to probable technological advancement, the most relevant ones, which also hold the highest numbers in employment, are expected to do so.

In addition to the increase of the employment rates, the national budget is expected to experience a positive increment due to tax revenues. Currently there are 35 states that are exploring hydraulic fracturing, from which 23 of those have severance taxes. Severance taxes are imposed on the removal of nonrenewable resources such as crude oil, condensate and natural gas, coalbed methane and carbon dioxide.[13] These severance taxes, also known as gross production taxes, charged to producers, or anyone with a working or royalty interest, in oil or gas operations in imposing the states and help not only ensure the longevity and adequate consumption of the natural resources, but also the overall federal revenue. The IHS Cambridge Energy Research Associates (IHS CERA) study findings additionally indicates that government revenues will be affected with more than $16 billion in 2015 (up from $13 billion in 2012) and rise to about $23 billion in 2025 [12].

While these taxes are applicable for most of the producing states, their value based on the type of natural resource varies. Based on the National Conference of State Legislatures (NCSL) 2012 databases, taxes related to oil and gas production and consumption fluctuate between 1 to 9 percent of the gross value [14].

## National Economic Security: Production Rates and Foreign Dependency

While these numbers denote a promising future for the American professionals and laborers involved with the fracturing industry in addition to the U.S. government revenues, the expanded application of hydraulic fracturing has also provided the country with less dependency from foreign suppliers and more financial security. Throughout its history, the United States has been heavily depended on foreign importations of energy resources. Because over the years, the U.S. was only able to produce an insufficient amount of energy compared to the total demand, the national economy has always been a hostage of oversees resources and external affairs' agreements.

With the start of hydraulic fracturing and the popularity in application it gained in the last decade, the United States production rates have increased significantly. According to the CIA World Factbook, in 1990, the country produced around 70 quadrillion Btu of energy, a number which remained fairly steady through 2006, with a total production of 69.443 quadrillion Btu. From 2006 to 2011, the total domestic production of natural gas increased with a difference of almost 10 quadrillion Btu. As hydraulic fracturing became more popular, the production rates increased to an additional of 19 quadrillion Btu per year in the beginning of 2007 and kept increasing with a production reaching an additional 23.608 quadrillion Btu in 2011, making USA the second largest natural gas producer in 2011, just behind Russia [15].

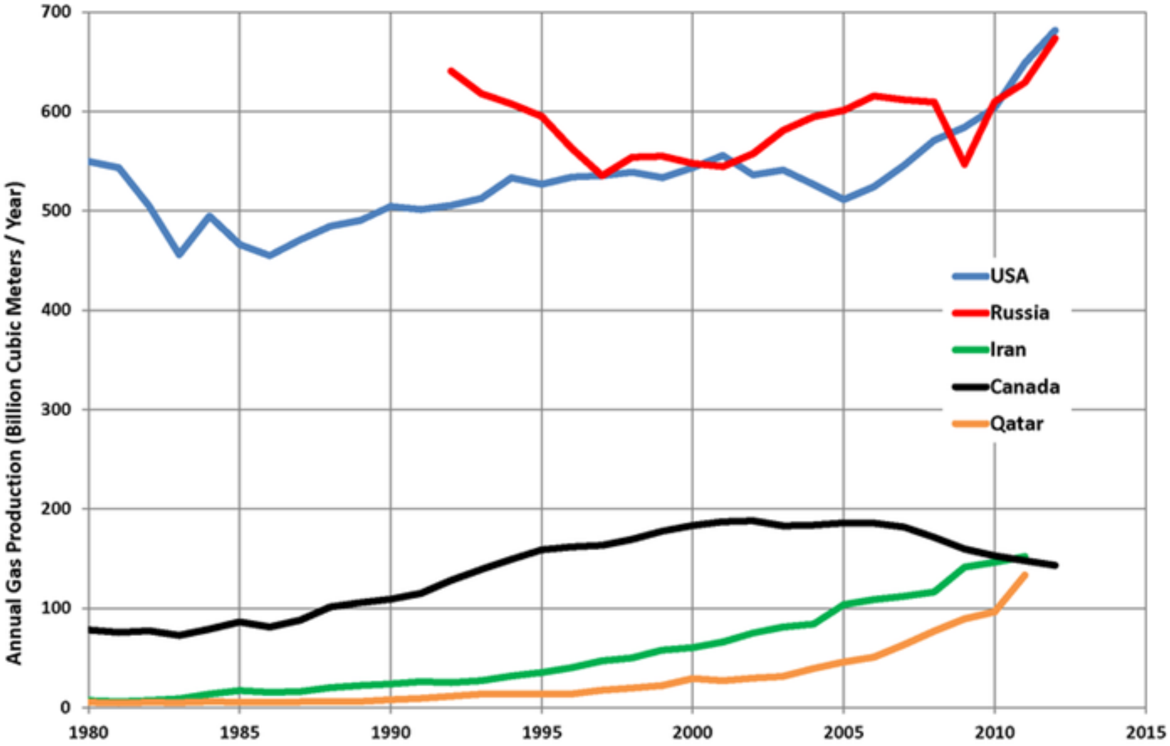


*Figure 6 - Annual Gas Production of Major Producers[74]*

As for 2013, United States was able to become the world's largest natural gas producer with an additional production of 24.7 quadrillion Btu according to U.S. Energy Information Administration [16].

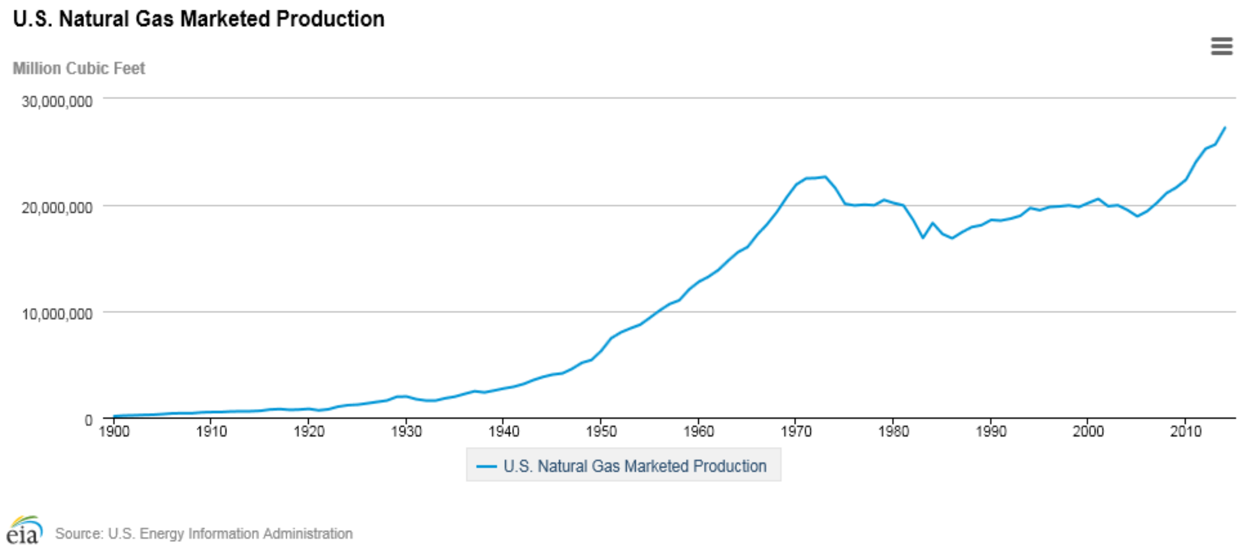


*Figure 7 - U.S. Natural Gas Marketed Production[74]*

As it can be seen from the graph above in Figure 7, beginning of 2005-2006, starting years of the hydraulic fracturing boom, the natural gas production rates have increased almost exponentially.

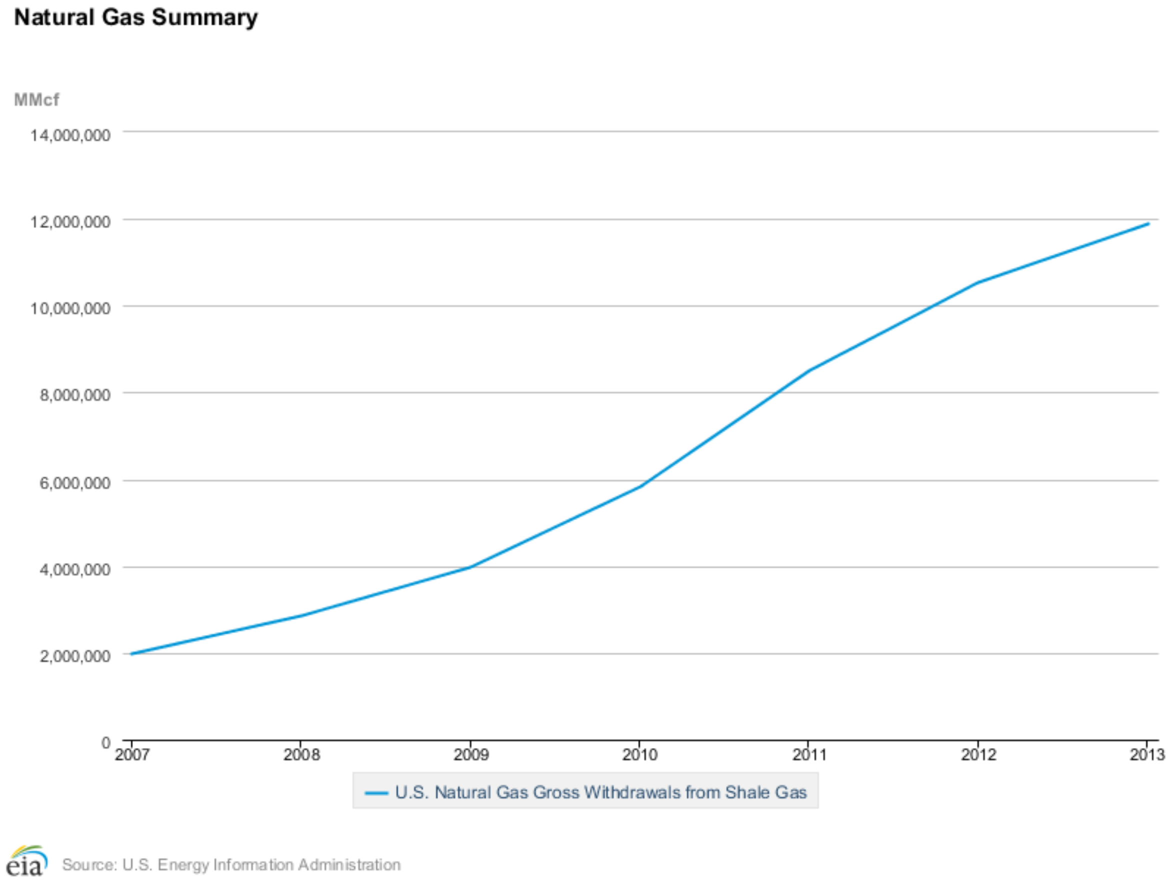


*Figure 8 - U.S. Natural Gas Gross Withdrawals from Shale Gas*[74]

As for the natural gas withdrawals from shale gas starting from 2007, displayed in Figure 8 above, the production rates indicate a pretty steady increase but with a substantial progressive slope.

The high production of energy over the past years due to natural gas extraction, previously thought inaccessible, has provided the country with more financial security and independence. From the Figure 9 below, this is clearly visible, as the energy import rates have highly decreased starting in 2007.

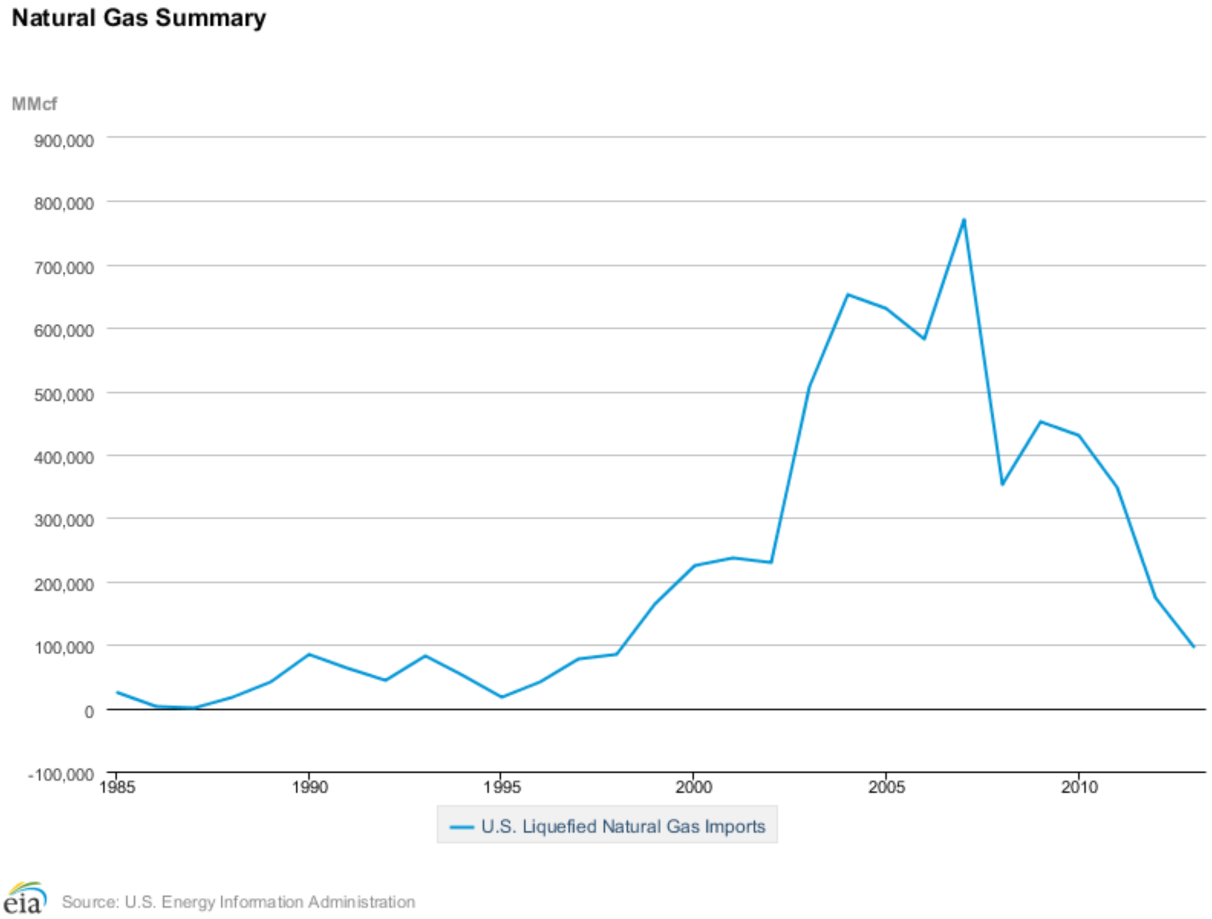
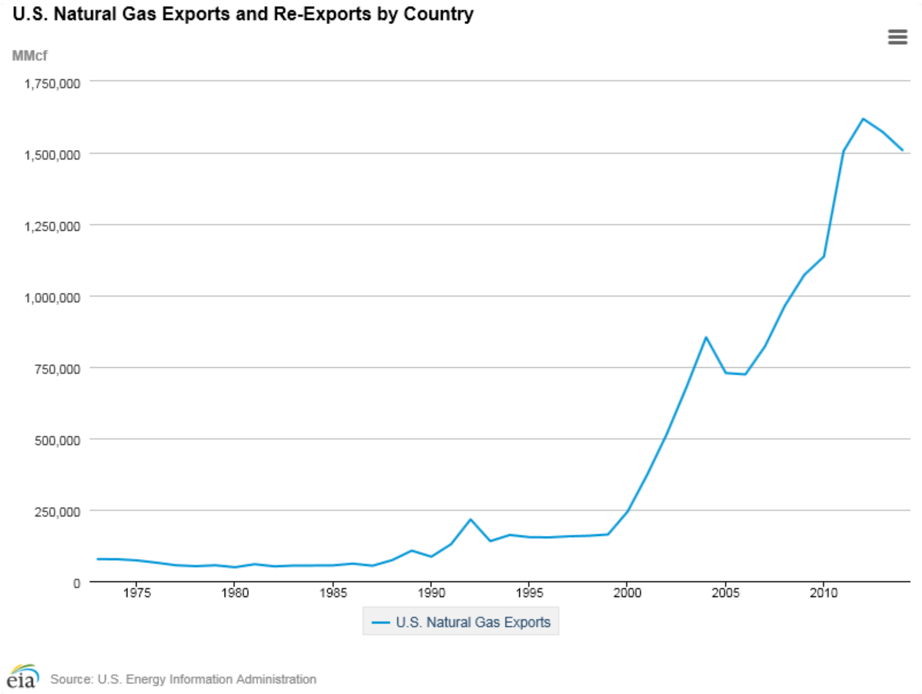


*Figure 9 - U.S. Liquefied Natural Gas Imports*[74]

Not only have the imports decreased, but the natural gas exports starting after 2000 have increased almost exponentially. This is illustrated in Figure 10.


U.S. Natural Gas Exports and Re-Exports by Country

Source: U.S. Energy Information Administration

*Figure 10 - U.S. Natural Gas Exports*[74]

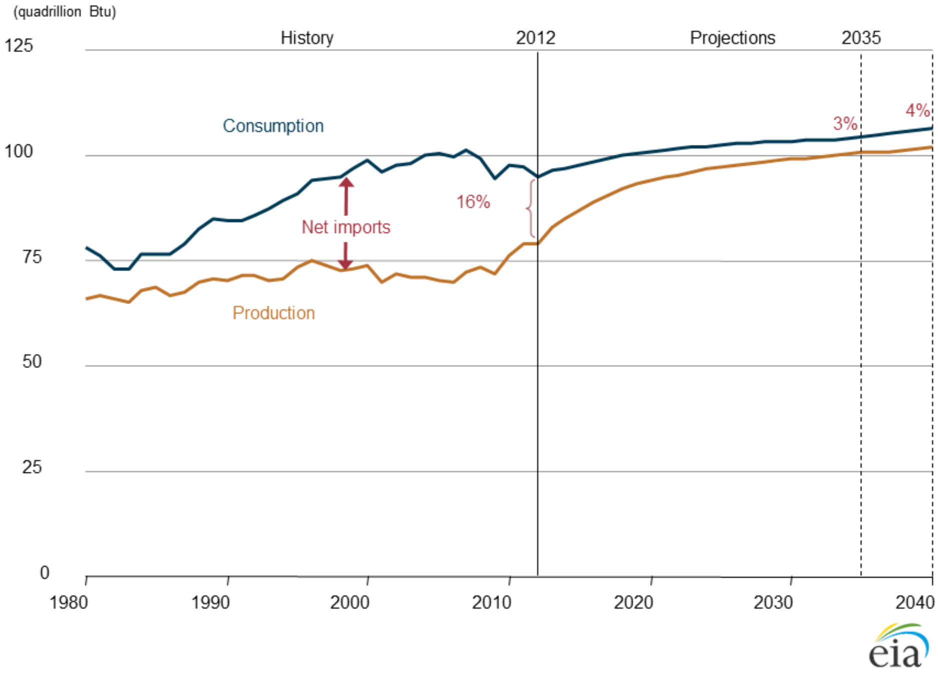


*Figure 11 - Total Energy Production and Consumption*[74]

It should be noted that the overall amount exported over the last years couldn’t compensate for the large amounts imported throughout the years. However, the production level seems to be catching up to the total consumption in the forthcoming decades. These promptly increasing rates, as displayed in Figure 11 above, not only guarantee a healthier federal budget, but also a future less contingent on external imports.

# Environmental Impacts

Hydraulic fracturing certainly has some economic benefits. However, it is not benign. Hydraulic fracturing operations are large-scale operations where substantial amount of water and chemicals are used in order to create fissures in the formations to recover trapped oil and gas. Injecting water and chemicals into oil wells is not without risks. There are potentials for contaminations of water aquifers and air quality. Water usage and waste management are huge concerns because improper handling can lead to extremely damaging to the environment.

## Water

Water is the primary component of hydraulic fracturing fluids. It is the component that carries all chemicals and proppants into the formations. Water makes up approximately 95%-99% of the total mixture. [9] The demand for water is extremely high in areas where oil and gas production is high.

## Water Usage Regulations

In many states, before carrying out hydraulic fracturing operations, operators must apply for permits in order to use large quantity of water. Although, federal regulations exempt hydraulic fracturing operations from the Safe Drinking Water Act, state authorities are taking necessary actions to make sure that their water resources are protected. For example, in July 2012, the Susquehanna River Basin Commission suspended approximately 64 water withdrawal permits due to concerns that water resources would be depleted as record heat waves hit Pennsylvania.[17] Table 1 below shows the locations and operating companies that had their water withdrawal permits suspended. This action demonstrates that state authorities take necessary steps to ensure that their water resources are protected when necessary.

| Company & Withdrawal | Location |
|---|---|
| **SWEPI LP**: Chemung River at Big Flats | Chemung, NY |
| **Talisman Energy USA Inc.**: Chemung River at Chemung | Chemung NY |
| **Smith Transport Warehouse**: Bald Eagle Creek | Blair, PA |
| **Chesapeake Appalachia**: Sugar Creek, Chemung River at Barrett | Bradford, PA |
| **Healthy Properties**: Sugar Creek | Bradford, PA |
| **Southwestern Energy Production Company**: Wyalusing Creek | Bradford, PA |
| **Talisman Energy**: Fall Brook at Bense,Seeley Creek at Jones, Susquehanna River at Welles, Towanda Creek from Franklin Twp. Volunteer Fire Department,unnamed tributary of North Branch Sugar Creek at Besley, Wappasening Creek at Adriance, Wyalusing Creek | Bradford, PA |
| **Tennessee Gas Pipeline Company**: Towanda Creek (Loop 317) | Bradford, PA |
| **Towanda Country Club** | Bradford, PA |
| **Carrizo**: Mosquito Creek | Clearfield, PA |
| **Chevron Appalachi**a: Clearfield Creek | Clearfield, PA |
| **KMI**: West Branch Susquehanna River | Clearfield, PA |
| **XTO Energy**: West Branch Susquehanna River | Clinton, PA |
| **Linde Corporation**: Lackawanna River | Lackawanna, PA |

| | |
|---|---|
| **Pine Meadows Golf Complex** | Lebanon, PA |
| **Cedar Rock Materials Corp.**: Bower Quarry | Luzerne, PA |
| **Eagle Rock Community Association / Eagle Rock Resort**: Quarry | Luzerne, PA |
| **EXCO Resources**: Muncy Creek at McClintock, West Branch Susquehanna River at Johnson | Lycoming, PA |
| **Hughesville-Wolf Township JMA**: wastewater | Lycoming, PA |
| **Keystone Clearwater Solutions**: Lycoming Creek-2 | Lycoming, PA |
| **Pennsylvania General Energy Company**: Pine Creek at Poust | Lycoming, PA |
| **XTO Energy**: Lick Run, Little Muncy Creek | Lycoming, PA |
| **Ultra Resources**: Pine Creek | Potter, PA |
| **Buck Ridge Stone**: Salt Lick Creek | Susquehanna, PA |
| **Cabot Oil & Gas**: Susquehanna River - 2 (Susquehanna Depot Boro.), Susquehanna River - 3 (Great Bend Twp.) | Susquehanna, PA |
| **Carrizo**: East Branch Wyalusing Creek, unnamed tributary to Middle Branch Wyalusing Creek | Susquehanna, PA |
| **Chesapeake Appalachia**: Elk Lake Stream | Susquehanna, PA |
| **Leonard and Jean Marie Azaravich**: Meshoppen Creek | Susquehanna, PA |
| **Southwestern Energy Production Company**: Tunkhannock Creek at Lenox | Susquehanna, PA |
| **Stone Energy Corporation**: Wyalusing Creek | Susquehanna, PA |
| **Tennessee Gas Pipeline Company**: Meshoppen Creek (Loop 319), White Creek (Loop 319) | Susquehanna, PA |

| | |
|---|---|
| **WPX Energy Appalachia**: Snake Creek | Susquehanna, PA |
| **Keystone Clearwater Solutions**: Babb Creek | Tioga, PA |
| **LDG Innovation**: Lawrenceville | Tioga, PA |
| **SWEPI LP**: Cowanesque River at Egleston; Cowanesque River at Westfield, Tioga River at Tioga Junction | Tioga, PA |
| **Tennessee Gas Pipeline Company**: Tioga River (Loop 315), unnamed tributary to North Elk Run (Loop 315) | Tioga, PA |
| **Ultra Resources**: Cowanesque River | Tioga, PA |
| **Sugar Hollow Trout Park and Hatchery**: hatchery water | Wyoming, PA |
| **Carrizo**: Meshoppen Creek | Wyoming, PA |
| **Chesapeake Appalachia**: Susquehanna River at Salsman | Wyoming, PA |
| **Mountain Energy Services**: Tunkhannock Creek | Wyoming, PA |
| **Randy M. Wiernusz**: Bowman Creek | Wyoming, PA |
| **Shadow Ranch Resort**: Tunkhannock Creek at Shadowbrook Resort | Wyoming, PA |
| **Sugar Hollow Water Services**: Susquehanna River at Chellis | Wyoming, PA |
| **Susquehanna Gas Field Services**: Meshoppen Creek | Wyoming, PA |
| **KBK-HR Associates LLC / Honey Run Golf Club** | York, PA |

*Table 1 - List of Companies and Their Approved Withdrawal Sources Suspended in July, 2012* [17]

## Water Regulations in Pennsylvania

Pennsylvania State sits on top of the Marcellus Shale, which is one of the highest producing shale formations in the United States.[18] Naturally, water usage is a concern as unregulated usage can lead to devastating consequences. Therefore, in Pennsylvania, strict water usage regulations are imposed on oil and gas producers. Prior to drilling an oil and gas well, the operator must submit an application for a permit. The application includes a map, showing locations of nearby water supplies. These are required to be at least 200 feet from any drinking water supplies.[19] However, water supply owner can waive this requirement. Section 208 of the Pennsylvania Oil and Gas Act states that well operators must restore or replace any polluted water supply.[19] Pollution of any water supply is determined by the Pennsylvania Department of Environmental Protection (DEP). Well operators are presumed to be responsible for water supplies pollution if it occurs within six months after completion or alterations of the well unless they use one of the following defenses[19]:

- The water supply is more than 1,000 feet from the oil/gas well.
- The water supply was already polluted prior to drilling operations.
- The landowner refused to allow operator to conduct pre-drilling water quality test.
- The pollution is not the result of gas well drilling
- The pollution occurred more than six months after the operation.

Due to these possible defenses, most operators hire independent state-certified laboratories to conduct pre-drilling water quality tests.

## Freshwater

Since the water used in the hydraulic fracturing operations is always mixed with other chemicals, water with high purity is desired. Freshwater is therefore the ideal candidate to use as the base liquid. Although these operations use several millions gallons of water per day, the total amount is approximately 1% of the total water usage in the United States according to statistics from the United States Geological Survey study on water usage in 2010.[20] According to the same study, approximately 42.8% of the total water withdrawal for mining, oil and gas in 2010 is freshwater.[20]

## Brine

Brine is a solution of salt in water. Brine is sometimes used as the base fluid in hydraulic fracturing. Brine the most common base fracturing fluid because sometimes hydraulic fracturing companies would reuse flowback water; water recovered after a fracturing operation, which is essentially brine.[21] Brine requires more chemicals to make it the appropriate viscosity for fracturing operations than water.

## Water Contamination

In 2010, the U.S. Congress directed the U.S. Environmental Protection Agency (EPA) to conduct a study regarding the potential impacts on the drinking water resources near the fracturing regions. This study plans to research the full lifespan of water in hydraulic fracturing [22]. While no contamination cases caused by hydraulic fracturing are disclosed by EPA and the final report is yet to be published, a review directed by the Associated Press showed that a substantial number of complaints alleging oil and natural gas drilling polluted or affected private water wells have been filed among the residents of the affected areas. These areas include

Pennsylvania with 106 water-well contamination cases; Ohio with 377 complaints in 2010 and no confirmed cases of water contaminations, 54 complaints in 2011 and two confirmed cases of contamination, 59 complaints in 2012 and two confirmed contaminations, 40 complaints in 2013 and two confirmed contaminations; West Virginia with 122 complaints; Texas with more than 2,000 complaints and 62 alleged possible well-water contaminations from oil and gas activity [23]. Although a number of those complaints have been confirmed by state officials to be unrelated to hydraulic fracturing. However, many remain unsolved. No specific and detailed information was published of what the contaminants were.

## Methane Contamination

A viral video of a man lighting his faucet on fire has raised concerns that hydraulic fracturing operations are causing methane to be released into the water aquifers. This video is featured in an anti-hydraulic fracturing film called “Gasland”. In the film, homeowner Mike Markham is shown lighting his faucet on fire. This film attracted wide attention. Soon after the film’s release, the Colorado Oil and Gas Conservation Commission (COGCC) launched an investigation regarding the claim that hydraulic fracturing is contaminating public drinking water.[24] The COGCC determined that the methane found in Mr. Markham’s drinking water well is of a biogenic nature, which means that the methane is produced by either bacteria or by geologic processes, not from oil and gas operations.[24] The COGCC has officially marked the complaint as resolved.

## Waste Management

It is estimated that the flowback recovery of hydraulic fracturing fluid can vary from as low as 25 percent to as high as 75 percent.[25] The rest of the fluid is permanently removed from the hydrologic cycle. The flowback from these oil wells need to be handled with care as they contain the original fracturing fluids as well as fluids and minerals that were in the fractured formations. Once the flowback has been recovered, operators have the options to either reuse the flowback or to discard it. If the flowback is to be reused, it is usually stored on-site and undergoes filtration in order to separate the liquid from the minerals and other solids in the mixture.[26] The filtered brine is then mixed with either more brine or freshwater in order to reach the required volume of liquid necessary for the next operation. If the operators choose to discard the flowback then it is transported to a nearby water treatment facility in order to be treated according to strict state and federal regulations. Once the water is deemed to be treated and safe, it is released into a designated water source. Treated water could also be disposed of in Class II Injection wells.[11]

## Chemical Hazards

One of the major environmental concerns of hydraulic fracturing is the hazardous substance used in the process to further increase the efficiency of the fluid. Even with regulations to minimize the exposure of the environment to these chemicals, there is potential for accidents. If they were to occur, the residents nearby would specifically suffer from the exposure of abnormal amounts of natural gas and possibly groundwater contamination in the case of hydraulic fracturing.

The danger of the chemicals used in hydraulic fracturing can be measured with the provided Material Safety Data Sheet (MSDS) with ratings in either the Hazardous Materials Identification System (HMIS) or the National Fire Protection Association (NFPA). These two identification systems both use a range from 0 to 4 for the categories of health, flammability and reactivity, 0 being the least hazardous and 4 being the most hazardous. Unlike the HMIS, the NFPA identification system assumes there is a fire in the premises, therefore the rating for each category can be different for the exact same chemical.

The rating in the health category for the HMIS identification system are as follows:

4. Life-threatening, major or permanent damage may result from single or repeated overexposures.
3. Major injury likely unless prompt action is taken and medical treatment is given.
2. Temporary or minor injury may occur.
1. Irritation or minor reversible injury possible.
0. No significant risk to health.

The rating in the health category for the NFPA identification system are as follows:

4. Material that on very short exposure could cause death or major residual injury.
3. Material that on short exposure could cause serious temporary or residual injury.
2. Material that on intense or continued but not chronic exposure could cause temporary incapacitation or possible residual injury.
1. Material that on exposure would cause irritation but only minor residual injury.
0. Material that on exposure under fire conditions would offer no hazard beyond that of ordinary combustible material.

In the case of analyzing data, the HMIS seems more appropriate for gauging the danger posed by the chemicals as there is no fire present, and if there is no information for HMIS, the NFPA will be used instead.

As hydraulic fracturing has been performed more than one million times in the United States[27], gathering statistical information for all the chemicals of each individual well would be overwhelming. However, this report includes statistical data obtained from 3 wells from each of the three major shale formations known as Barnett, Marcellus and Bakken.

The Barnett Shale is a geological formation in the Bend Arch-Fort Worth Basin, Texas. The formation spans over 5,000 $mi^2$ throughout at least 17 counties, and is believed to hold 2.5 trillion cubic feet of recoverable natural gas, and with a total of 30 trillion cubic feet of natural gas.[28] However, the natural gas is only recoverable through hydraulic fracturing because the ground surrounding the natural gas is impermeable. Without advancements in technology in regards to hydraulic fracturing, the extraction of the natural gas was virtually impossible. The shale in 2014 produced on average 4.9 billion cubic feet of natural gas per day.[29]

The Marcellus Shale is another geological formation that extends throughout the Appalachian Coast, which covers 104,000 $mi^2$ across Pennsylvania and West Virginia, also inclusive of southeast Ohio and upstate New York. This geological formation has been theorized to hold 50 trillion cubic feet of recoverable natural gas, to a total of 500 trillion cubic feet of natural gas, also with impermeable conditions.[30] As of 2014, the shale produced on average 14 billion cubic feet of natural gas per day.[31]

The Bakken Shale, the last of the geological formations to be discussed, is located below the Williston Basin. The basin covers 200,000 $mi^2$ and belongs to parts of Montana, North Dakota, Saskatchewan and Manitoba, and is more known for oil production than for natural gas production. In 2013, the US Geological Survey estimated the recovery of 7.4 billion barrels of recoverable oil, with a total of up to 24 billion barrels of oil due to the low permeability of the formation.[32] As of the end of 2010, the formation has produced on average of 458,000 barrels of oil per day.[33] Hydraulic fracturing, based on the statistical information obtained from the three major shale formations have used hazardous chemicals in their formula (refer to Figures 12, 13, and 14 below, compiled by us). The figures represent the count of the different levels of hazardous chemicals used in each wells of the major shale, Barnett, Marcellus and Bakken. The initial three figures have been labeled by the title with the major shale, the horizontal axis with the randomly chosen wells from the shale, the vertical axis with the count of each hazardous chemical, and the color coding to describe the hazard rating, elaborated upon in the above section. The representation of N/A is used to describe chemicals that do not have any representation, either by MSDS or chemical secrecy. Chemical secrecy is state dependent, displayed below the shale figures.

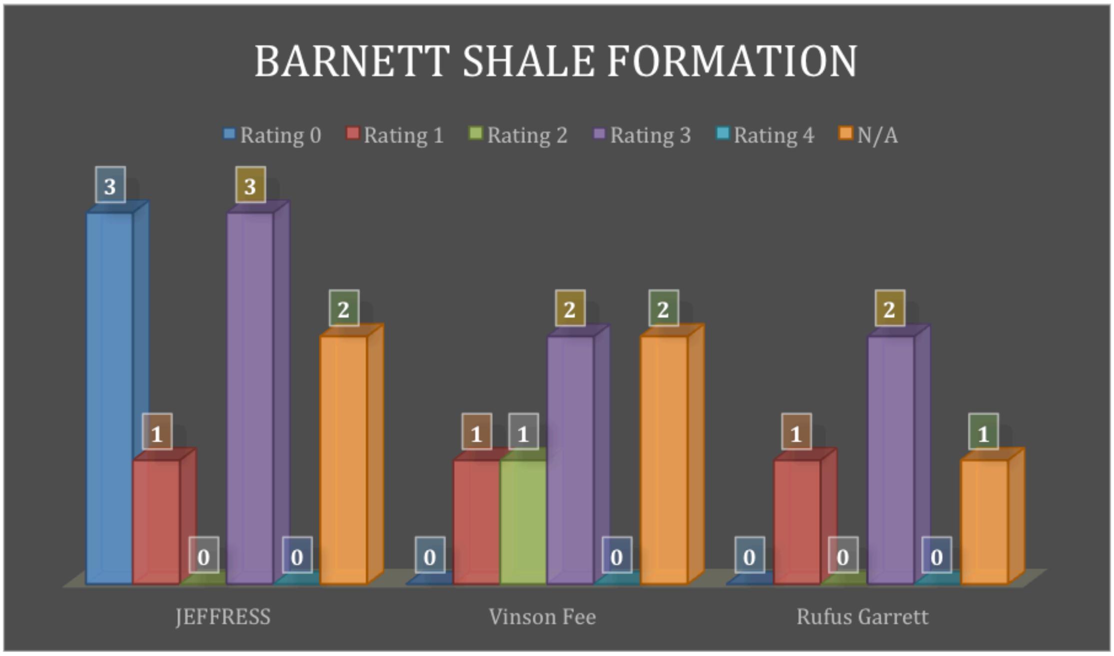


*Figure 12 - Histogram of Chemical Hazard Ratings from 3 Randomly Selected Wells in the Barnett Shale*

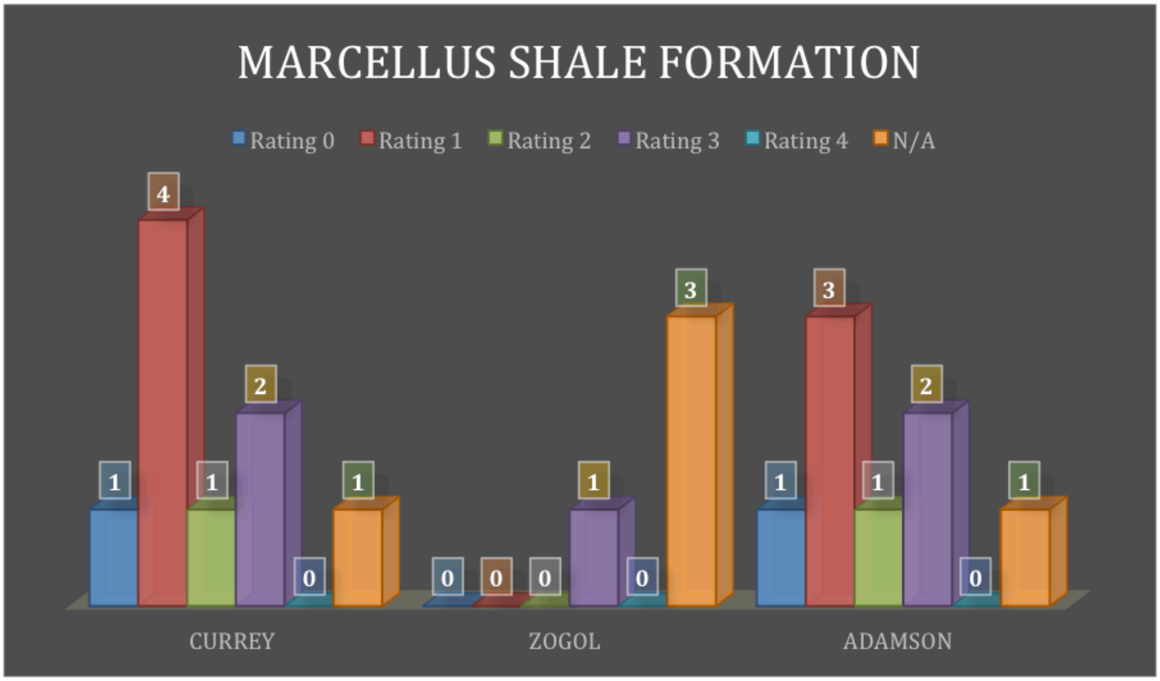


*Figure 13 - Histogram of Chemical Hazard Ratings from 3 Randomly Selected Wells in the Marcellus Shale*

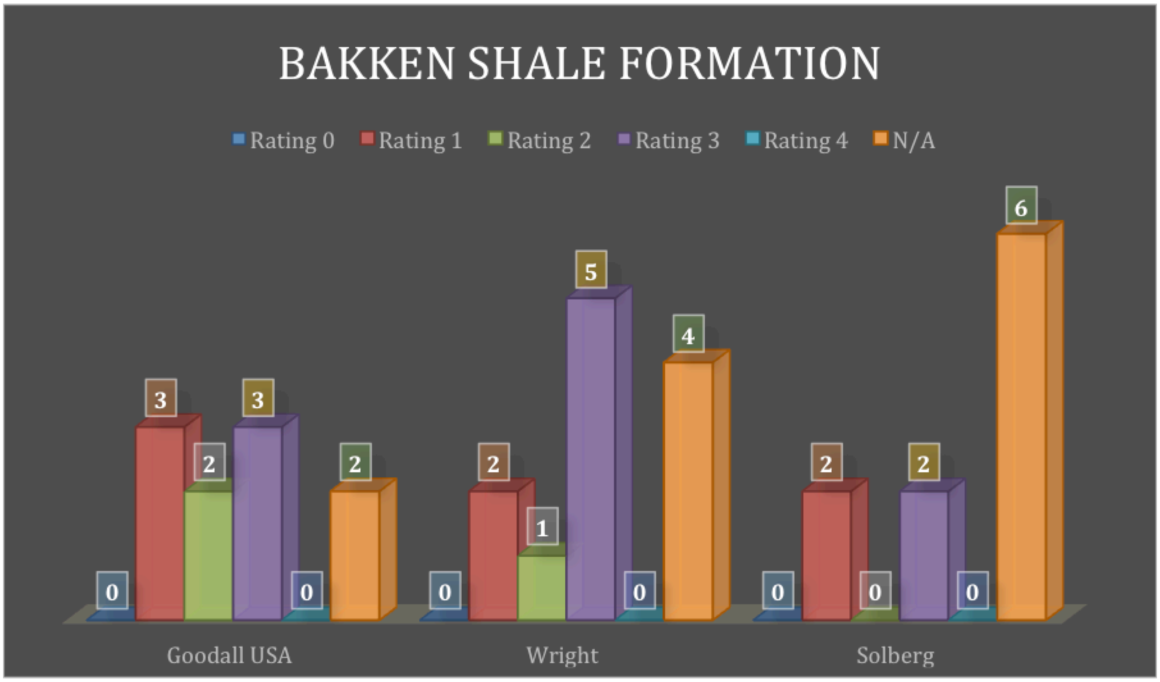
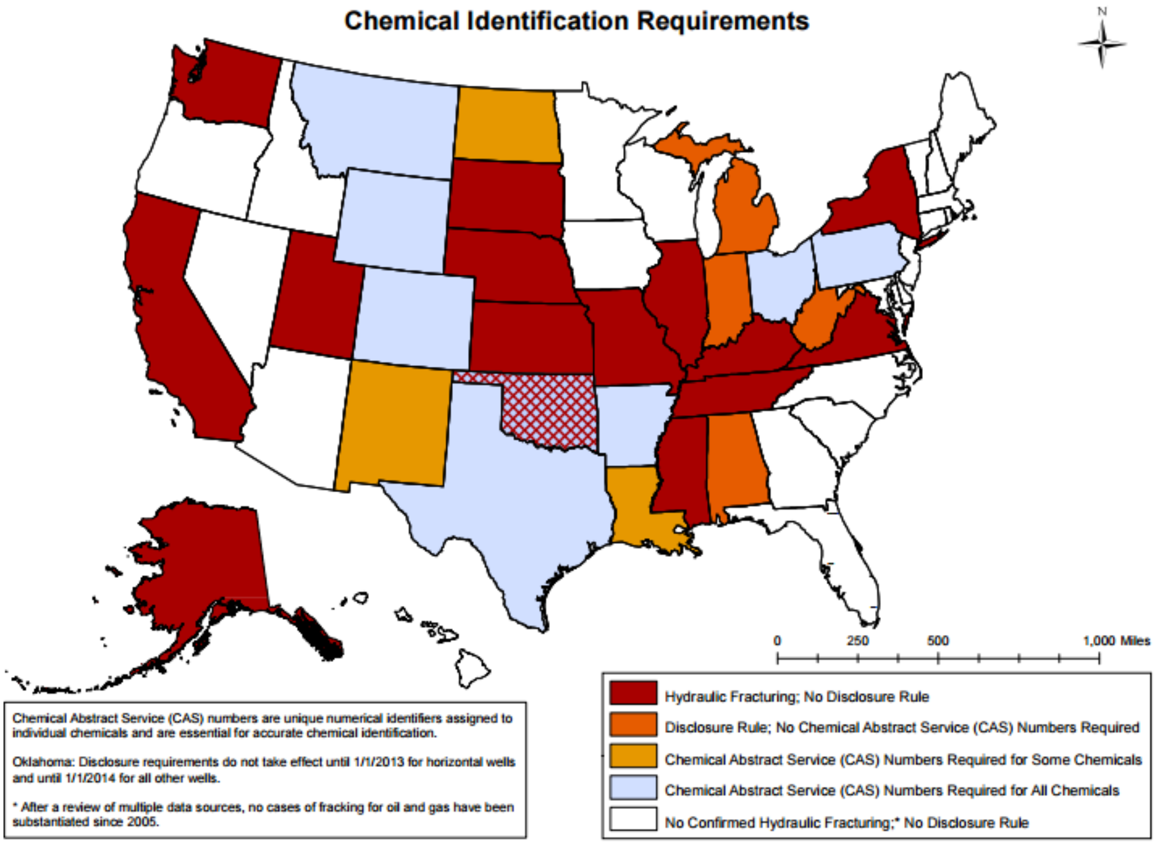


*Figure 14 - Histogram of Chemical Hazard Ratings from 3 Randomly Selected Wells in the Bakken Shale*



Chemical Abstract Service (CAS) numbers are unique numerical identifiers assigned to individual chemicals and are essential for accurate chemical identification.

Oklahoma: Disclosure requirements do not take effect until 1/1/2013 for horizontal wells and until 1/1/2014 for all other wells.

* After a review of multiple data sources, no cases of fracking for oil and gas have been substantiated since 2005.

*Figure 15 - Chemical Identification Requirements by State*[73]

With the figures represented above from the information given through fracfocus.org, the randomly selected wells did not contain any chemicals that pertain to the hazard rating of 4, chemicals that would cause major or permanent damage from single or multiple exposures. Furthermore, the MSDS for each chemical used in the hydraulic fracturing fluid contains methods of exposure, which could be used to determine the potential threat.

The circumstances to which hydraulic fracturing fluids can be harmful to the human population can be determined through three stages. The first stage is that the hydraulic fracturing fluid must leak through the well casing regulated by each specific state requirements.[34] Second being that the hydraulic fracturing fluid is close enough in proximity to contaminate groundwater despite the set regulations by the state. Lastly, the person must be exposed to the chemical by a certain method that pertain dangers.

## United States Laws

Following the concerns of the public, the United States has implemented laws to strengthen the regulations to limit the possible exposure of chemicals to the public. The laws limiting hydraulic fracturing are actually those of each individual state, rather than the federal laws, which have loopholes in which the regulations of fracturing can be worked around.

Additionally, with the discussion of laws regarding the processes of hydraulic fracturing, there are two key concepts that will provide clarity. These key concepts are that the federal laws that are explained here are specifically assorted for hydraulic fracturing, and that the federal laws can overrule the state laws.

Since hydraulic fracturing is the topic of interest, the laws that pertain to general processes used by oil and gas industries that lead up to hydraulic fracturing is not interpreted. The reason behind not considering these general processes is because they are sufficient enough to extract oil and/or gas without introducing methods such as hydraulic fracturing, which means these processes are independent of hydraulic fracturing. Furthermore, there are many techniques other than just hydraulic fracturing that oil and gas companies can use to further extract resources. This means that these laws to not apply explicitly to hydraulic fracturing, and that there are plenty of loopholes in laws with regards to oil and gas industry while not being explicitly beneficial to hydraulic fracturing.[35]

Another useful concept is located in the provision known as the Supremacy Clause in Article Six, Clause 2 of the United States Constitution known as the doctrine of preemption. [35] The doctrine states that with a conflict between federal law and state law, the federal law always prevails. A case of the federal law prevailing can be observed in the Arizona immigration law.

When Arizona passed a strict immigration law, it has international implications which provoked the federal government into action, overriding the state law implemented.[36][37][38] Despite the federal government's authority, the feds do not always intervene when state laws and federal laws contradict. An example of such conflict between the federal law and the state law can be witnessed with the legalization of prostitution in certain counties of Nevada [39], which is illegal according to the federal laws as a form of human trafficking.

## Hydraulic Fracturing: Loopholes in Federal Laws

As previously mentioned, federal laws have loopholes, which allow hydraulic fracturing companies to work around, and below are examples of such.

### *Safe Drinking Water Act*

The Safe Drinking Water Act (SDWA) was enacted in 1974 to preserve America's groundwater resources. This law encompasses both water that is used and water that may be used for drinking purposes, whether they are above or below ground. Due to the nature of hydraulic fracturing and its injection of a variety of substances at high pressures into the ground, it is considered as a threat to the groundwater resources. Regardless, the SDWA was amended by the Energy Policy Act in 2005 to provide more flexibility to which the oil and gas companies can operate. [40] The amendment defined "underground injection" to exclude any fluids or proppant agents other than diesel fuel, which means anything other than diesel fuel can be used with hydraulic fracturing operations without having to adhere to the provisions of the SDWA. The amendment was based upon the research of the Congressional Research Service, which considered hydraulic fracturing to not be a potential danger to underground drinking water sources.[41]

### *Emergency Community Right to Know Act*

The Emergency Community Right to Know Act (EPCRA) of 1986 is designed to protect public health and the environment from chemical hazards. The EPCRA acts to document and report information to the public on the chemicals stored, used, released, or disposed. The Toxic Release Inventory (TRI) created by the EPCRA uses guidelines to select industries to report their significant use of toxic substances to the EPA. The report is then assorted into a public database that contains information on toxic releases and waste management activities reported facilities under the guidelines.[42] However, the list that the EPA issues of the industries that must report releases for the database is not inclusive of the oil and gas industry. This is not an exemption in the law, rather it is a decision by the EPA that this industry is not a high priority for reporting under the TRI. Moreover, the chemicals used in hydraulic fracturing is protected by the concept of Trade Secrets under the EPCRA.[43] This section has permitted chemical manufacturers to deem that the hydraulic fracturing fluids used are proprietary, without the need to disclose information.[44] However, the lack of disclosure must meet a set criteria to determine whether the identity of the chemical is of crucial essence to be kept secret for business' competitive position. Furthermore, the trade secrets can be disclosed in certain circumstances for health requests stated in the EPCRA.[45]

### *Resource Conservation and Recovery Act*

The Resource Conservation and Recovery Act (RCRA), passed in 1976, is a regulatory foundation in managing solid waste, including hazardous waste. This regulation takes on a "cradle to grave" approach, ensuring that these wastes are handled from their point of creation, through their transportation, and towards their storage and/or disposal. However, due to the Solid

Waste Disposal Act (SWDA) of 1980, oil and gas exploration and production wastes were exempted from regulation for at least two years, to which was announced that the EPA would conduct studies to determine whether such wastes should be regulated as hazardous waste under the RCRA.[46] In 1988, the EPA then formally stated that the regulation of oil and gas exploration and production wastes under the RCRA Subtitle C is unnecessary due to the fact that each states have their own circumstances.[47] Given these conditions, wastes from hydraulic fracturing are not regulated by federal law because of the inadequate flexibility obtained by passing one general law over fifty states. As a result, the federal government passed the responsibility of regulation to the state government, determining that oil, gas and geothermal production was already in regulation by each state.[48][49]

### *Comprehensive Environmental Response, Compensation, and Liability Act (Superfund Program)*

The Superfund program was established by the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) in 1980 to ensure that parties responsible for the release of hazardous substances into the environment are held accountable. Despite these efforts, the oil and gas companies are exempt for being liable for their cleanup under the CERCLA if any hazardous materials are contained within petroleum, including crude oil, natural gas liquids, liquefied natural gas and mixtures of natural gas and synthetic gas.[50] The exemption is due to the basis that these chemicals are used for natural gas production.[51] The result of exemption leads to little incentive to clean up hazardous waste and minimize leaks and spills which could be witnessed from the incident at Campbell Country in 2006. [52][53] The incidents were reported to consist five spills, and leakages from a valve left open on the storage tank. Furthermore, the Superfund trust fund that is acquired from the taxes imposed on oil and chemical industries is used to pay for cleanup when no responsible party can be identified. The fund falls short of supplying project goals due the abolishment of taxes by the Congress and is funded by the general tax revenue.[53]

## Hydraulic Fracturing: State Regulations

These regulations of the state abide by the concerns of the public, enforcing stricter regulations to contain the possible exposure from hydraulic fracturing.

### *Pennsylvania*

As of July 2013, Pennsylvania has stated several regulations towards hydraulic fracturing.[54][55]

1. **Drilling permits** – To drill anywhere in the state of Pennsylvania, oil and gas companies must obtain a drilling permit which would require a submission of environmental risk analysis to Pennsylvania's Department of Environmental Protection (DEP). Furthermore, all surface water supply owners within 1,000 feet of the drill site must be notified, and operators must submit a deposit or bond to the state as security against the violation of environmental regulations and restrictions.
2. **Drilling distances** – Pennsylvania's environmental regulation states that gas drilling must not occur within 200 feet of drinking water supplies, within 100 feet of any surface water, or within 100 feet of any wetland greater than one acre in size.
3. **Water testing and drinking water replacement** – Operators are responsible to replace or resolve any loss of drinking water due to contamination from drilling operations under the Oil and Gas Act, when it occurs within 1,000 feet from the well in question and within 6 months after well completion.

4. **Water quantity** – Operators are also responsible for the water supply used as fluids in hydraulic fracturing. Landowners who experience diminished water quality due to hydraulic fracturing may request an investigation from the Pennsylvania Department of Environmental Protection (DEP). Furthermore, under the Oil and Gas Act, companies are required to restore or replace drinking water supplies used by gas drilling activities.
5. **Groundwater contamination** – The state has implemented regulations controlling construction and standards for well casings to reduce leakages.
6. **Well closing** – The integrity of well's casing protecting groundwater must be maintained and verified before the well is further processed with well closing.
7. **Act 13** – Operators are required to disclose hydraulic fracturing chemicals to the DEP and publications of these disclosures on FracFocus.org. Furthermore the act also states an agreement that state regulations will trump municipal laws.

### *Texas*

Along with Pennsylvania, Texas has also presented regulations for hydraulic fracturing operations.[56][57][58]

1. **Drilling permit** – In the state of Texas, any operator that wishes to operate on an oil and gas well must apply for a permit which states that the operators may not pollute surface water or groundwater in the state.
2. **Well integrity** – The Railroad Commission of Texas (RRC) enacted rules to enforce higher standards for oil and gas well construction. The law explains and updates requirements concerning cementing, well casing, steel piping and specifications for hydraulic fracturing.

3. **Chemical disclosure** – The RRC passed a law requiring operators to disclose information about the chemicals used in hydraulic fracturing. The rule requires the Texas oil and gas operators to disclose information on FracFocus.org, regarding chemical ingredients used and the volume of water used in hydraulic fracturing treatments.[59]
4. **Well closing** – All wells must be plugged back to avoid contamination or harm.

### *New York*

The state of New York is a special case, as it has recently banned hydraulic fracturing on December 17, 2014. This ban, based on the potential environmental impacts associated with hydraulic fracturing has convinced the Governor Andrew M. Cuomo that hydraulic fracturing does impose health risks to the state. He agreed with the fact that he would not live in a community that allows hydraulic fracturing and would not want his children to be around such a place.[60]

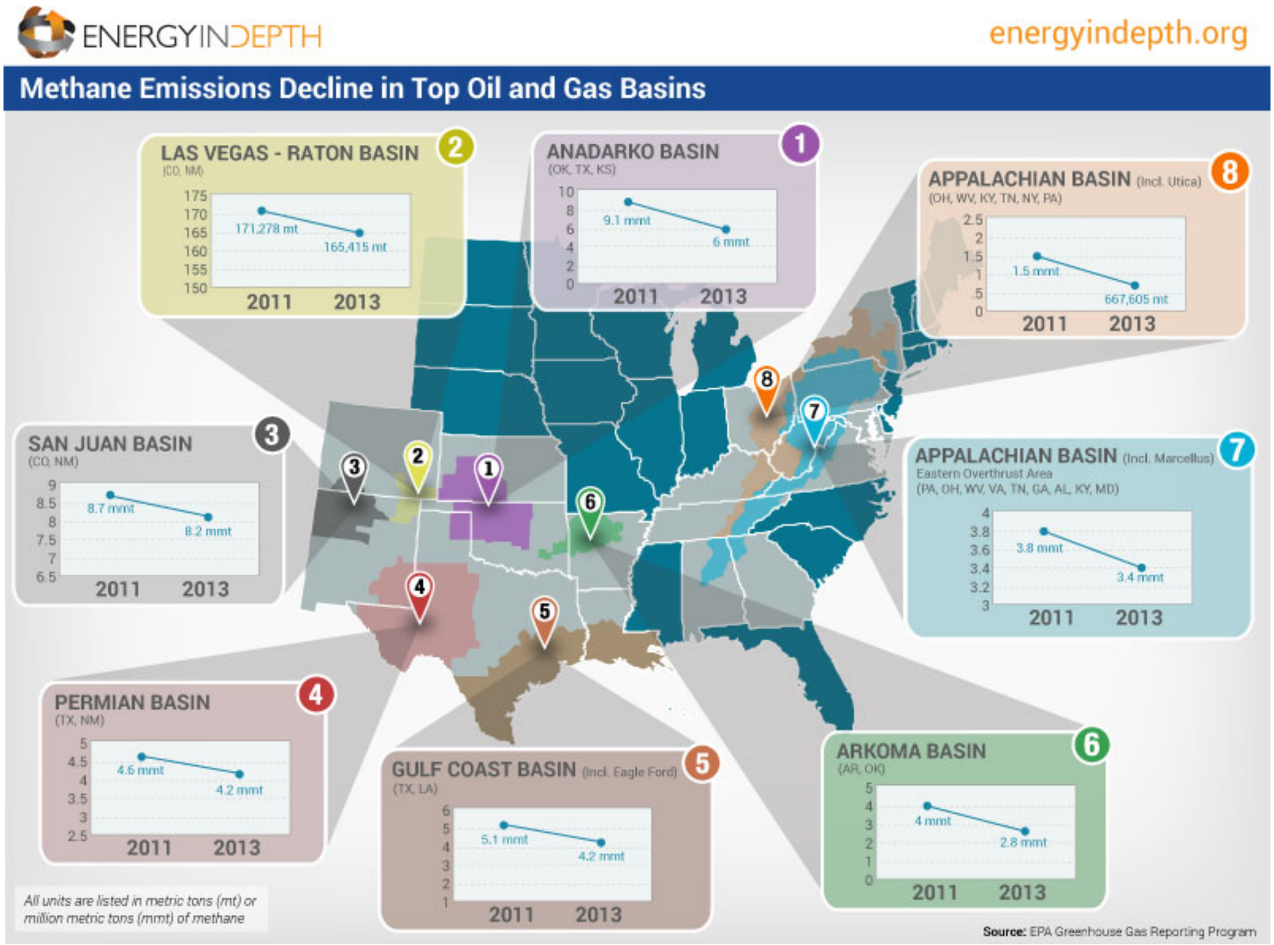
## Public Concerns

The public concerns associated with hydraulic fracturing are primarily fixed on the potential dangers towards the health and safety of the people in the proximity of fracturing wells. The main dangers suggested with hydraulic fracturing are groundwater contamination and seismic activity. These concerns have led to disputes about the possible tradeoffs of hydraulic fracturing, and multiple studies to review the plausibility of these concerns.

### Does hydraulic fracturing expose groundwater to further contamination?

There are two main types of groundwater contamination concerned with hydraulic fracturing. The first concern is addressed to the fear of increased concentrations of methane in the air leaking from the water valves, and the second unease is of contamination of drinking water from the chemicals used for hydraulic fracturing.

There has been no proven correlation that hydraulic fracturing has unconditionally increased the concentration levels of methane in groundwater when regulatory measures have been set. Rather, each of the individual shales in the U.S. have been accredited for their reduction in methane emissions.



All units are listed in metric tons (mt) or million metric tons (mmt) of methane

**Source:** EPA Greenhouse Gas Reporting Program

*Figure 16 - Methane Emissions from Basins Experiencing Hydraulic Fracturing*[75]

Furthermore, according to the Environmental Protection Agency's (EPA) recent Greenhouse Gas inventory[61], methane emissions from natural gas productions have generally fallen by 35 percent since 2007. This decrease in emissions is happening in concurrence with the 400 percent increase in the U.S. shale gas production within a similar timeline. These reduction in emissions, noted by the EPA, are through the cause of voluntary actions by producers implementing modern technology.

The fear of increased concentrations of methane is through the appliance of high pressures in hydraulic fracturing, theoretically inducing possible leakages of methane. During the early usage of hydraulic fracturing, the possibility of methane leaking into the underground sources of drinking water (USDW) had people concerned for their well-being. The fear is stemmed by the lack of proper reference for the baseline water chemistry, there was no possible way to establish the fact that hydraulic fracturing had not contaminated the USDW with increased the levels of methane emissions. An example of such would be in Pennsylvania, where there has been a history of methane with the usage of water through methane migration. However, when intensified drilling in 2008 seemingly produced a heightened amount of methane in groundwater, there were no records to compare the actual changes in the methane levels.[62] Additionally, this lack of reference is also attributed to the fear of chemical contamination in groundwater.

In June 2014, a study by Public Health England examined the potential public health issues from exposures to chemical and radioactive pollutants from shale gas extraction from existing data from countries that have used hydraulic fracturing, it was concluded that the potential risks of exposure to emissions from shale gas extraction is minimal if the operations are properly run and regulated.[63] Furthermore, evidence from the study proposes that contamination of groundwater does not occur in the process of hydraulic fracturing, but rather through the leakage of the vertical borehole. The indicated risks of leakage have been generally reported as a consequence of a poor regulations.

## Can hydraulic fracturing be associated with the increased seismic events?

The nature of hydraulic fracturing is injecting liquids at high pressures to create fractures for the gas or oil to seep through. This process does induce seismic activity, but it is important to distinguish that these are minor seismic events that cannot be felt, and would not cause damage at the surface.[64] Hydraulic fracturing does not appear to be associated with the increased rate of earthquakes with magnitudes of 3 or higher, based upon an analysis of the U.S. Geological Survey database for earthquakes by a team of scientists led by Bill Ellsworth.[65] Nor can hydraulic fracturing be directly associated with land subsidence, but may occur through production of oil, natural gas or groundwater.[78] It is important to note that the seismic activity of magnitude 3 earthquake is similar to the passing of a truck. However, the trend of increased earthquakes do coincide with the injection of wastewater into underground wastewater disposal wells.[65] Even when the association of seismic activity is related to wastewater disposal wells, the Environmental Protection Agency (EPA) states that very few of the disposal wells have produced significant seismic events with magnitudes greater than 4. As an example, the EPA declares that approximately 2,700 active disposal wells in Louisiana have no recent significant seismic events occurring as a result of the activities.[66]

## Why does the federal government not regulate hydraulic fracturing activities?

As mentioned in more detail in the laws and regulations section, the federal law supersedes the state law if actively enforced. If the federal laws are enforced, the hydraulic fracturing activities could be monitored and regulated by the federal government. However, each state has its own circumstances to which enforcing the regulations would be more efficient if the laws were state dependent. Upon this belief, the federal government has allowed the states to regulate hydraulic fracturing activities.

## Alternative Methods

Allowing for all the attention that controversial debates have poured on the impacts of hydraulic fracturing on the environment and overall society, many companies everyday more are showing interest in finding more efficient and environment-friendly methods of extracting shale resources. Although this report focuses on the process of extracting shale gas through hydraulic fracturing, taking in consideration the increased need for energy, an innovative technique for extracting fossil energy in shale level will be discussed.

Raytheon, a major American defense company with headquarters in Waltham of Massachusetts, in partnership with CF Technologies, a company focused in the Critical Fluid Processes with headquarters in Hyde Park of Massachusetts, have developed a new technology that combines radio frequency waves with supercritical fluids in order to process the oil trapped deep in shale formation[68]. This technology was later acquired from Schlumberger; the world's largest oilfield services company with headquarters in Houston, Texas.

### Process of Radio Frequency (RF) Heating of Oil Shale (RF-CF technique)

The innovative microwave heating technology implements radio frequency heating for shale oil processing. These radio frequency waves are transmitted into the core molecule of oil shale and changed to heat energy. Using only RF transmission and no direct heat conduction, all the molecules are heated in the same from inwards as well as outwards. Microwave absorbing materials are added in order to increase oil's the absorbance of the electromagnetic waves. Such materials help the bituminous matter of the oil shale to reach a thermal degradation state that is necessary for it to be fractured into gas and oil. The oil and gas produced is then retrieved through wells up to the surface.[67]

The material used in this case, differently from earlier shale oil heating techniques, is a fluid in its critical state. These critical fluids, also known as supercritical fluids (SCF), are liquids or gases that are forced to pass their critical point (both critical temperature and critical pressure). Once they enter this state, they have properties of both gases and fluids. They are similar to gases in viscosity, diffusivity, compressibility, and no surface tension and similar to fluids in density and solvency. Having such physical characteristics they are able to penetrate the sedimentary rock formation and help the RF heating dissolve the kerogen [68].

# Conclusions

After a thorough analysis of the procedure, economic benefits, potential environmental risks, public concerns and regulations, it was concluded that through proper regulations, the benefits of growth of employment and higher energy independency resulting from increased oil and natural gas production in the U.S. outweigh the potential concerns of water contamination, seismic activity, waste management, and water usage. Although this was the consensus of the paper, the resulting effect on the future of hydraulic fracturing depends on the opinions of multiple groups.

## Industry Opinion

Hydraulic fracturing has been a popular well stimulation technique. It is a way to greatly enhance oil and gas recovery from otherwise unrecoverable oil and gas deposits. Hydraulic fracturing operations have impacted not only new oil wells but old wells too. Oil deposits that have previously been deemed uneconomical to recover have been re-evaluated and extracted because of hydraulic fracturing. According to information on the benefits of hydraulic fracturing, it is clear that the industry will continue to grow. There are many benefits that come from hydraulic fracturing. These benefits include higher employment rates within the industry, lower energy price due to the decrease of gas and oil imports, lower dependency on foreign energy and politics, as well as a considerable improvement of the national budget. The benefits are evident and show no sign of diminishing.

## Public Opinion

The future of hydraulic fracturing depends heavily on public opinions. Anti-hydraulic fracturing movement in New York is a good example of how negative opinions towards hydraulic fracturing can impact the industry. Although advantages of hydraulic fracturing seem to outweigh disadvantages, companies involved in the hydraulic fracturing business must ensure the public that everything that can be done to reduce the risks that are presented with these operations is being implemented out in the field. Companies must gain the trust and confidence of the public if they are to survive.

## Regulations

Despite the general public's opinion that hydraulic fracturing companies are free to do as they wish, current regulations provide adequate oversight on hydraulic fracturing operations. New regulations have been introduced in recent years to promote transparency and remove loopholes. Analysis of both federal and state regulations demonstrates that state regulations, in general, are far stricter than federal regulations and they hold hydraulic fracturing companies accountable for their actions. Each state has its own regulatory committee that oversees all hydraulic fracturing operations and they are pro-active in addressing the issues of transparency in chemical usage. Companies are required to disclose all chemicals used in these operations while the criteria for claiming chemicals as confidential business information are becoming more demanding.

## Media

It is true with any industry that one of the biggest contributors to their image is the media. The future of hydraulic fracturing depends on how the media portrays the advantages and disadvantages of hydraulic fracturing. It is the media's responsibility to provide accurate and unbiased opinion. Throughout the process of writing this paper, it's been clear that there are many media sources that only cover damaging stories about hydraulic fracturing, because they attract more interest. It is more difficult to find out about the benefits of hydraulic fracturing. People are led to believe that there are only disadvantages from hydraulic fracturing.

# Appendix I – Example of Chemicals Used in Hydraulic Fracturing[72]

## Bakken Shale

### Well name: Goodall USA #11-29H

| | |
|---|---|
| **Fracture Date** | **1/14/2011** |
| **State:** | **ND** |
| **County:** | **McKenzie** |
| **API Number:** | **33-053-03192** |
| **Operator Name:** | **Marathon** |
| **Well Name and Number:** | **Goodall USA #11-29H** |
| **Longitude:** | **-102.620567** |
| **Latitude:** | **47.964419** |
| **Long/Lat Projection:** | **NAD83** |
| **Production Type:** | **Oil** |
| **True Vertical Depth (TVD):** | **10,632** |
| **Total Water Volume (gal)*:** | **1,066,939** |

| **Trade Name** | **Supplier** | **Purpose** | **Ingredients** | **Chemical Abstract Service Number (CAS #)** | **Maximum Ingredient Concentration in Additive ( by mass)**** | **Maximum Ingredient Concentration in HF Fluid ( by mass)**** |
|---|---|---|---|---|---|---|
| | | | | | | |
| Water | Operator | Carrier | Water | 7732-18-5 | 100.00 | 74.96029 |
| | | | | | | |
| Frac Sand (All Meshes) | BHI | Proppant | Crystalline Silica (Quartz) | 14808-60-7 | 100.00 | 24.23972 |

| | | | | | | |
|---|---|---|---|---|---|---|
| CWT | | | | | | |
| | | | | | | |
| GBW-5 | BHI | Breaker | Ammonium Persulfate | 7727-54-0 | 100.00 | 0.00025 |
| | | | | | | |
| Enzyme G-I | BHI | Breaker | Hemicellulase Enzyme Concentrate | 9025-56-3 | 3.00 | 0.00050 |
| | | | Water | 7732-18-5 | 97.00 | 0.01610 |
| | | | | | | |
| GBW-23L | BHI | Breaker | White Mineral Oil | 8042-47-5 | 91.00 | 0.05283 |
| | | | Magnesium Hydroxide | 1309-42-8 | 5.00 | 0.00290 |
| | | | Magnesium Peroxide | 14452-57-4 | 3.00 | 0.00174 |
| | | | Magnesium Oxide | 1309-48-4 | 2.00 | 0.00116 |
| | | | | | | |
| Alpha 452 | BHI | Biocide | Tetrakis(hydroxymethyl) Phosphonium Sulfate | 55566-30-8 | 40.00 | 0.00940 |
| | | | | | | |
| GW-3LDF | BHI | Gellant | Petroleum Distillate Blend | CBI | 70.00 | 0.34405 |
| | | | Guar Gum | 9000-30-0 | 40.00 | 0.19660 |
| | | | | | | |
| Scalesorb 3 | BHI | Scale Inhibitor | Calcined Diatomaceous Earth | 91053-39-3 | 100.00 | 0.02792 |
| | | | Amino Tri (Methylene Phosphonic Acid) | 6419-19-8 | 30.00 | 0.00838 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | Phosphonic Acid | 13598-36-2 | 1.00 | 0.00028 |
| | | | Crystalline Silica Quartz | 14808-60-7 | 1.00 | 0.00028 |
| | | | | | | |
| XLW-30AG | BHI | Crosslinker | Hydrotreated Light Distillate | 64742-47-8 | 70.00 | 0.04303 |
| | | | | | | |
| Inflo 250W | BHI | Surfactant | Surfactants | CBI | 80.00 | 0.03003 |
| | | | 2-Butoxyethanol | 111-76-2 | 20.00 | 0.00751 |
| | | | Methanol | 67-56-1 | 30.00 | 0.01126 |
| | | | | | | |
| NE-900 | BHI | Non-emulsifier | Methanol | 67-56-1 | 30.00 | 0.01124 |
| | | | Nonyl Phenyl Polyethylene Glycol Ether | 9016-45-9 | 10.00 | 0.00375 |
| | | | | | | |
| XLW-32 | BHI | Crosslinker | Boric Oxide | 1303-86-2 | 90.00 | 0.00986 |
| | | | Methanol | 67-56-1 | 20.00 | 0.00219 |
| | | | | | | |
| BF-9L | BHI | Buffer | Potassium Hydroxide | 1310-58-3 | 15.00 | 0.01873 |

* Total Water Volume sources may include fresh water, produced water, and/or recycled water

** Information is based on the maximum potential for concentration and thus the total may be over 100

All component information listed was obtained from the supplier's Material Safety Data Sheets (MSDS). As such, the Operator is not responsible for inaccurate and/or incomplete information. Any questions regarding the content of the MSDS should be directed to the supplier who provided it. The Occupational Safety and Health Administration's (OSHA) regulations govern the criteria for the disclosure of this information. Please note that Federal Law protects "proprietary", "trade secret", and "confidential business information" and the criteria for how this information is reported on an MSDS is subject to 29 CFR 1910.1200(i) and Appendix D.

### Well name: Solberg 31-2WH

| | |
|---|---|
| Job Start Date: | 12/12/2014 |
| Job End Date: | 12/22/2014 |
| State: | North Dakota |
| County: | Williams |
| API Number: | 33-105-03371-00-00 |
| Operator Name: | Whiting Petroleum |
| Well Name and Number: | Solberg 31-2WH |
| Longitude: | -103.11858380 |
| Latitude: | 48.37161780 |
| Datum: | NAD83 |
| Federal/Tribal Well: | NO |
| True Vertical Depth: | 10,131 |
| Total Base Water Volume (gal): | 1,795,962 |
| Total Base Non Water Volume: | 0 |

| Trade Name | Supplier | Purpose | Ingredients | Chemical Abstract Service Number (CAS #) | Maximum Ingredient Concentration in Additive (% by mass)** | Maximum Ingredient Concentration in HF Fluid (% by mass)** |
|---|---|---|---|---|---|---|
| Fresh Water | Operator | Carrier Fluid | | | | |
| | | | Water | 7732-18-5 | 100.00000 | 86.81289 |
| Proppant (Sand) | RockPile Energy | Propping Agent | | | | |
| | | | Crystalline Silica, quartz | 14808-60-7 | 100.00000 | 7.35244 |
| Proppant (LWC) | RockPile Energy | Propping Agent | | | | |
| | | | Mullite | 1302-93-8 | 60.00000 | 2.68209 |
| Proppant (LWC) | RockPile Energy | Propping Agent | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | Cristobalite | 14464-46-1 | 30.00000 | 1.34105 |
| Proppant (LWC) | RockPile Energy | Propping Agent | | | | |
| | | | Amorphous Silica | 7631-86-9 | 15.00000 | 0.67052 |
| 15% HCl | RockPile Energy | Acid | | | | |
| | | | Water | 7732-18-5 | 85.00000 | 0.62377 |
| Ecopol-2000LMS | RockPile Energy | Water Gelling Agent | | | | |
| | | | Petroleum Distillates (Mineral Oil) | 64742-47-8 | 55.00000 | 0.16646 |
| Ecopol-2000LMS | RockPile Energy | Water Gelling Agent | | | | |
| | | | Guar Gum | 9000-30-0 | 50.00000 | 0.15133 |
| 15% HCl | RockPile Energy | Acid | | | | |
| | | | Hydrochloric Acid | 7647-01-0 | 15.00000 | 0.11008 |
| Ecopol DBXL-90 | RockPile Energy | Crosslinker | | | | |
| | | | Petroleum Distillates (Mineral Oil) | 64742-47-8 | 55.00000 | 0.06109 |
| Ecopol-NE601 | RockPile Energy | Non-emulsifying Agent | Methanol | 64-17-5 | 50.00000 | 0.05947 |
| | | | | | | |
| Ecopol DBXL-90 | RockPile Energy | Crosslinker | | | | |
| | | | Ulexite | 1319-33-1 | 50.00000 | 0.05554 |
| Ecopol-NE601 | RockPile Energy | Non-emulsifying Agent | | | | |
| | | | Water | 7732-18-5 | 30.00000 | 0.03568 |
| Ecopol-NE601 | RockPile | Non-emulsifying | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Energy | Agent | | | | |
| | | | Coconut Diethanolamide | 68603-42-9 | 25.00000 | 0.02974 |
| Ecopol-EC101 | RockPile Energy | Crosslinker | | | | |
| | | | Ethylene Glycol | 107-21-1 | 55.00000 | 0.01927 |
| Econo-CS35 | RockPile Energy | Activator | | | | |
| | | | Water | 7732-18-5 | 80.00000 | 0.01925 |
| Ecopol-NE601 | RockPile Energy | Non-emulsifying Agent | | | | |
| | | | Triethylene Glycol | 112-27-6 | 15.00000 | 0.01784 |
| Ecopol-EC101 | RockPile Energy | Crosslinker | | | | |
| | | | Water | 7732-18-5 | 30.00000 | 0.01051 |
| Ecopol-2000LMS | RockPile Energy | Water Gelling Agent | | | | |
| | | | Organophilic Clay | 68953-58-2 | 3.00000 | 0.00908 |
| Econo-FR400 | RockPile Energy | Friction Reducer | | | | |
| | | | Water | 7732-18-5 | 40.00000 | 0.00896 |
| Ecopol-EC101 | RockPile Energy | Crosslinker | | | | |
| | | | Potassium Metaborate | 13709-94-9 | 25.00000 | 0.00876 |
| Econo-CS35 | RockPile Energy | Activator | | | | |
| | | | Sodium Hydroxide | 1310-73-2 | 35.00000 | 0.00842 |
| Econo-FR400 | RockPile Energy | Friction Reducer | | | | |
| | | | Acrylamide and Acrylic Acid | 25987-30-8 | 30.00000 | 0.00672 |
| | | | Copolymer | | | |
| Econo-FR400 | RockPile | Friction Reducer | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Energy | | | | | |
| | | | Mineral Oil | 64742-47-8 | 25.00000 | 0.00560 |
| AC-100 | RockPile Energy | Corrosion inhibitor | | | | |
| | | | Water | 7732-18-5 | 75.00000 | 0.00522 |
| EconoCap-HP | RockPile Energy | Breaker | | | | |
| | | | Ammonium Persulfate | 7727-54-0 | 75.00000 | 0.00375 |
| Ecopol-EC101 | RockPile Energy | Crosslinker | | | | |
| | | | Potassium Hydroxide | 1310-58-3 | 10.00000 | 0.00350 |
| Ecopol-EC101 | RockPile Energy | Crosslinker | | | | |
| | | | Sodium Hydroxide | 1310-73-2 | 10.00000 | 0.00350 |
| Ecopol DBXL-90 | RockPile Energy | Crosslinker | | | | |
| | | | Organophilic Clay | 68953-58-2 | 3.00000 | 0.00333 |
| Ecopol DBXL-90 | RockPile Energy | Crosslinker | | | | |
| | | | Ethoxylated Alcohol | 9043-30-5 | 3.00000 | 0.00333 |
| SI-202F | RockPile Energy | Iron control | | | | |
| | | | Water | 7732-18-5 | 50.00000 | 0.00227 |
| SI-202F | RockPile Energy | Iron control | | | | |
| | | | Citric Acid | 77-92-9 | 50.00000 | 0.00227 |
| Ecopol-2000LMS | RockPile Energy | Water Gelling Agent | | | | |
| | | | Ethoxylated Alcohol | 9043-30-5 | 0.50000 | 0.00151 |
| AC-100 | RockPile Energy | Corrosion inhibitor | | | | |
| | | | Propargyl Alcohol | 107-19-7 | 15.00000 | 0.00104 |
| EconoCap-HP | RockPile | Breaker | | | | |

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
|  | Energy |  |  |  |  |  |
|  |  |  | Resin Compound | 9002-85-1 | 15.00000 | 0.00075 |
| AC-100 | RockPile Energy | Corrosion inhibitor |  |  |  |  |
|  |  |  | Methanol | 67-56-1 | 10.00000 | 0.00070 |
| EconoCap-HP | RockPile Energy | Breaker |  |  |  |  |
|  |  |  | Crystalline Silica | 14808-60-7 | 10.00000 | 0.00050 |
| Econo-FR400 | RockPile Energy | Friction Reducer |  |  |  |  |
|  |  |  | Ammonium Chloride | 12125-02-9 | 2.00000 | 0.00045 |
| Econo-FR400 | RockPile Energy | Friction Reducer |  |  |  |  |
|  |  |  | Phosphate Esters of Alcohol Ethoxylate | 68585-36-4 | 2.00000 | 0.00045 |
| Econo-FR400 | RockPile Energy | Friction Reducer |  |  |  |  |
|  |  |  | Sorbitan Monooleate | 1338-43-8 | 2.00000 | 0.00045 |
| AC-100 | RockPile Energy | Corrosion inhibitor |  |  |  |  |
|  |  |  | Isopropanol | 67-63-0 | 1.00000 | 0.00007 |
| Ingredients shown above are subject to 29 CFR 1910.1200(i) and appear on Material Safety Data Sheets (MSDS). Ingredients shown below are Non-MSDS. |  |  |  |  |  |  |

* Total Water Volume sources may include fresh water, produced water, and/or recycled water

** Information is based on the maximum potential for concentration and thus the total may be over 100%

Note: For Field Development Products (products that begin with FDP), MSDS level only information has been provided.

Ingredient information for chemicals subject to 29 CFR 1910.1200(i) and Appendix D are obtained from suppliers Material Safety Data Sheets (MSDS)

## Well name: Wright 4-33 #1H

| | |
|---|---|
| **Fracture Date** | **8/4/2010** |
| **State:** | **North Dakota** |
| **County:** | **Mountrail** |
| **API Number:** | **3306101278** |
| **Operator Name:** | **BRIGHAM OIL & GAS LP** |
| **Well Name and Number:** | **Wright 4-33 #1H** |
| **Longitude:** | **-102.645184** |
| **Latitude:** | **48.270213** |
| **Long/Lat Projection:** | **NAD83** |
| **Production Type:** | **Oil** |
| **True Vertical Depth (TVD):** | **10,220** |
| **Total Water Volume (gal)*:** | **3,360,995** |

| **Trade Name** | **Supplier** | **Purpose** | **Ingredients** | **Chemical Abstract Service Number (CAS #)** | **Maximum Ingredient Concentration in Additive ( by mass)**** | **Maximum Ingredient Concentration in HF Fluid ( by mass)**** |
|---|---|---|---|---|---|---|
| Fresh Water | Operator | | | | 100.00 | 87.43572 |
| CERAMIC PROP | Halliburton | Proppant | Crystalline silica, cristobalite | 14464-46-1 | 30.00 | 2.23159 |
| | | | Mullite | 1302-93-8 | 100.00 | 7.43864 |
| | | | Silica, amorphous - fumed | 7631-86-9 | 30.00 | 2.23159 |
| SAND - PREMIUM WHITE | Halliburton | Proppant | Crystalline silica, quartz | 14808-60-7 | 100.00 | 4.89155 |
| CL-22 UC | Halliburton | Crosslinker | Potassium formate | 590-29-4 | 60.00 | 0.01636 |

| | | | | | | |
|---|---|---|---|---|---|---|
| CL-31 CROSSLINKER | Halliburton | Crosslinker | Potassium hydroxide | 1310-58-3 | 5.00 | 0.00045 |
| | | | Potassium metaborate | 13709-94-9 | 60.00 | 0.00542 |
| MO-67 | Halliburton | Buffer | Sodium hydroxide | 1310-73-2 | 30.00 | 0.00768 |
| LoSurf-300D | Halliburton | Surfactant | 1,2,4 Trimethylbenzene | 95-63-6 | 1.00 | 0.00077 |
| | | | Ethanol | 64-17-5 | 60.00 | 0.04638 |
| | | | Heavy aromatic petroleum naphtha | 64742-94-5 | 30.00 | 0.02319 |
| | | | Naphthalene | 91-20-3 | 5.00 | 0.00386 |
| | | | Poly(oxy-1,2-ethanediyl),alpha-(4-nonylp henyl)-omega-hydroxy-, branched | 127087-87-0 | 5.00 | 0.00386 |
| FR-66 | Halliburton | Friction Reducer | Hydrotreated light petroleum distillate | 64742-47-8 | 30.00 | 0.00668 |
| OPTIFLO-III DELAYED RELEASE BREAKER | Halliburton | Breaker | Ammonium persulfate | 7727-54-0 | 100.00 | 0.00650 |
| | | | Crystalline silica, quartz | 14808-60-7 | 30.00 | 0.00195 |
| OptiKleen-WF™ | Halliburton | Surfactant | Sodium perborate tetrahydrate | 10486-00-7 | 100.00 | 0.00291 |
| WG-36 GELLING AGENT | Halliburton | Gelling Agent | Guar gum | 9000-30-0 | 100.00 | 0.06321 |
| Biocide 5000 | JACAM | Antibacterial | Glutaraldehyde | 111-30-8 | 50.00 | 0.00277 |
| | | | Water | 7732-18-5 | 50.00 | 0.00277 |
| | | | Methanol | 67-56-1 | 0.50 | 0.00003 |
| WSI 3607 | JACAM | Scale Inhibitor | Proprietary Component | Proprietary Component | 100.00 | 0.06840 |
| | | | Ethylene Glycol | 107-21-1 | 100.00 | 0.06840 |
| | | | Methanol | 67-56-1 | 100.00 | 0.06840 |

| | | | | | | |
|---|---|---|---|---|---|---|
| WOS 1N | JACAM | Oxygen Scavenger | Proprietary Component | Proprietary Component | 100.00 | 0.00205 |
| | | | Ethylene Glycol | 107-21-1 | 100.00 | 0.00205 |

* Total Water Volume sources may include fresh water, produced water, and/or recycled water

** Information is based on the maximum potential for concentration and thus the total may be over 100

Ingredient information for chemicals subject to 29 CFR 1910.1200(i) and Appendix D are obtained from suppliers Material Safety Data Sheets (MSDS)

## Barnett Shale

## Well name: Vinson Fee F5

| | |
|---|---|
| Job Start Date: | 4/27/2013 |
| Job End Date: | 4/27/2013 |
| State: | Texas |
| County: | Wise |
| API Number: | 42-497-35271-00-00 |
| Operator Name: | XTO Energy/ExxonMobil |
| Well Name and Number: | Vinson Fee F5 |
| Longitude: | -97.47309700 |
| Latitude: | 32.99932500 |
| Datum: | NAD27 |
| Federal/Tribal Well: | NO |
| Total Base Water Volume (gal): | 644,574 |
| Total Base Non Water Volume: | |

| Trade Name | Supplier | Purpose | Ingredients | Chemical Abstract Service Number (CAS #) | Maximum Ingredient Concentration in Additive (% by mass)** | Maximum Ingredient Concentration in HF Fluid (% by mass)** |
|---|---|---|---|---|---|---|
| Sand | GoFrac | Proppant | | | | |
| | | | Crystaline Silica | 14808-60-7 | 100.00000 | 5.73484 |
| HCL 35% | Formosa Plastics | Hydrochloric Acid | | | | |
| | | | Water | 7732-18-5 | 65.00000 | 0.21962 |
| | | | Hydrogen Chloride | 7647-01-0 | 35.00000 | 0.11825 |
| Antimicrobial 220 | Frac-Chem | Biocide | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | Glutaraldehyde | 111-30-8 | 14.00000 | 0.00212 |
| | | | Didecyl Dimethyl Ammonium Chloride | 7173-51-5 | 3.00000 | 0.00045 |
| | | | Alkyl Dimethyl Benzyl Ammonium Chloride | 68424-85-1 | 3.00000 | 0.00045 |
| | | | Ethanol | 64-17-5 | 3.00000 | 0.00045 |
| Plexaid 673 | Chemplex | Scale Inhibitor | | | | |
| | | | Methyl Alcohol | 67-56-1 | 25.00000 | 0.00252 |
| Ferriplex 66 | Chemplex | Iron Control | | | | |
| | | | Acetic Acid | 64-19-7 | 50.00000 | 0.00052 |
| Plexhib 256 | Chemplex | Corrosion Inhibitor for HCL | | | | |
| | | | Methyl Alcohol | 67-56-1 | 40.00000 | 0.00030 |
| | | | Propargyl Alcohol | 107-19-7 | 8.00000 | 0.00006 |
| Plexbreak 145 | Chemplex | Non-Emulsifier | | | | |
| | | | Methyl Alcohol | 67-56-1 | 15.00000 | 0.00004 |
| Ingredients shown above are subject to 29 CFR 1910.1200(i) and appear on Material Safety Data Sheets (MSDS). Ingredients shown below are Non-MSDS. | | | | | | |
| | | Other Chemicals | | | | |
| | | | Water | 7732-18-5 | 100.00000 | 93.87153 |
| | | | Emulsion Polymer | Proprietary | 100.00000 | 0.02288 |
| | | | Petroleum Hydrotreated Light Distillate | 64742-47-8 | 99.00000 | 0.00554 |
| | | | Alcohol Ehoxylate Surfactants | Proprietary | 1.00000 | 0.00056 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | Citric Acid | 77-92-9 | 30.00000 | 0.00031 |
| | | | Organic Phophonic Acid Salts | Proprietary | | |

* Total Water Volume sources may include fresh water, produced water, and/or recycled water

** Information is based on the maximum potential for concentration and thus the total may be over 100%

Note: For Field Development Products (products that begin with FDP), MSDS level only information has been provided.

Ingredient information for chemicals subject to 29 CFR 1910.1200(i) and Appendix D are obtained from suppliers Material Safety Data Sheets (MSDS)

## Well name: Jeffress 3H

| | |
|---|---|
| **Fracture Date:** | 3/25/2011 |
| **State:** | TEXAS |
| **County:** | JOHNSON |
| **API Number:** | 4225134020 |
| **Operator Name:** | CHESAPEAKE |
| **Well Name and Number:** | JEFFRESS 3H |
| **Longitude:** | -97.316894 |
| **Latitude:** | 32.502513 |
| **Long/Lat Projection:** | NAD27 |
| **Production Type:** | GAS |
| **True Vertical Depth (TVD):** | 7,531 |
| **Total Water Volume (gal)*:** | 1,374,492 |

| **Trade Name** | **Supplier** | **Purpose** | **Ingredients** | **Chemical Abstract Service Number (CAS #)** | **Maximum Ingredient Concentration in Additive ( by Mass)**** | **Maximum Ingredient Concentration in HF Fluid ( by Mass)**** |
|---|---|---|---|---|---|---|
| Fresh Water | | Carrier/Base Fluid | | | | 87.82624 |
| Recycled Produced Water | | Carrier/Base Fluid | | | | 1.70877 |
| Sand (Proppant) | | Proppant | | | | 9.34561 |
| Acid, Hydrochloric 15pct | SCHLUMBERGER TECHNOLOGY | Acid | Water | 007732-18-5 | 85.00 | 0.83576 |
| | | | Hydrogen Chloride | 007647-01-0 | 15.00 | 0.14749 |
| L058 | SCHLUMBERGER TECHNOLOGY | Iron Control Agent | Sodium Erythorbate | 006381-77-7 | 100.00 | 0.00874 |

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
| A264 | SCHLUMBERGER TECHNOLO GY | Corrosion Inhibitor | Methanol (Methyl Alcohol) | 000067-56-1 | 40.00 | 0.00116 |
|  |  |  | Aliphatic acid | N/A | 30.00 | 0.00087 |
|  |  |  | Aliphatic alcohols, ethoxylated # 1 | N/A | 30.00 | 0.00087 |
|  |  |  | Propargyl Alcohol (2-Propynol) | 000107-19-7 | 10.00 | 0.00029 |
| Bactron K-87 Microbiocide | CHAMPION TECHNOLO GIES INC | Anti-Bacterial Agent | Glutaraldehyde (Pentanediol) | 000111-30-8 | 30.00 | 0.00666 |
|  |  |  | Alkyl dimethyl ethylbenzyl ammonium chloride (68C12, 32C14) | 085409-23-0 | 10.00 | 0.00222 |
|  |  |  | Quaternary Ammonium Compounds, benzyl-C12-18-alkyldimethyl, chlorides | 068391-01-5 | 10.00 | 0.00222 |
|  |  |  | Ethanol | 000064-17-5 | 1.00 | 0.00022 |
| Gyptron T-390 | CHAMPION TECHNOLO | Scale Inhibitor | Methanol (Methyl Alcohol) | 000067-56-1 | 10.00 | 0.00058 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | GIES INC | | | | | |
| MC B 8642 WS | MULTI-CHE M GROUP LLC | Anti-Bacterial Agent | Glutaraldehyde (Pentanediol) | 000111-30-8 | 60.00 | 0.00721 |
| | | | Quaternary Ammonium Compound | 068424-85-1 | 10.00 | 0.00120 |
| | | | Ethanol | 000064-17-5 | 1.00 | 0.00012 |
| MC S-2510T (WS) | MULTI-CHE M GROUP LLC | Scale Inhibitor | Ethylene Glycol | 000107-21-1 | 60.00 | 0.00581 |
| | | | Sodium Hydroxide | 001310-73-2 | 5.00 | 0.00048 |
| J580 | SCHLUMBERGER TECHNOLOGY | Gelling Agent | Carbohydrate polymer | N/A | 100.00 | 0.05827 |
| B315 | SCHLUMBERGER TECHNOLOGY | Friction Reducer | Petroleum Distillate Hydrotreated Light | 064742-47-8 | 30.00 | 0.02142 |
| | | | Aliphatic alcohol polyglycol ether | N/A | 1.50 | 0.00107 |
| J218 | SCHLUMBERGER TECHNOLOGY | Breaker | Ammonium Persulfate | 007727-54-0 | 100.00 | 0.00858 |
| J532 | SCHLUMBERGER TECHNOLOGY | Cross Linker | Aliphatic polyol | N/A | 40.00 | 0.00029 |
| | | | Sodium Tetraborate (Sodium | 001303-96-4 | 30.00 | 0.00021 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | Tetraborate Decahydrate) | | | |

* Total Water Volume sources may include fresh water, produced water, and/or recycled water

** Information is based on the maximum potential for concentration and thus the total may be over 100

All component information listed was obtained from the supplier's Material Safety Data Sheets (MSDS). As such, the Operator is not responsible for inaccurate and/or incomplete information.

Any questions regarding the content of the MSDS should be directed to the supplier who provided it. The Occupational Safety and Health Administration's (OSHA) regulations govern the criteria for the disclosure of this information. Please note that Federal Law protects "proprietary", "trade secret", and "confidential business information" and the criteria for how this information is reported on an MSDS is subject to 29 CFR 1910.1200(i) and Appendix D.

## Well name: Rufus Garrett A3

| | |
|---|---|
| **Fracture Date** | **6/17/2011** |
| **State:** | **Texas** |
| **County:** | **Denton** |
| **API Number:** | **42-121-30774** |
| **Operator Name:** | **Devon Energy** |
| **Well Name and Number:** | **Rufus Garrett A3** |
| **Longitude:** | **-97.38491** |
| **Latitude:** | **33.03117** |
| **Long/Lat Projection:** | **NAD27** |
| **Production Type:** | **Gas** |
| **True Vertical Depth (TVD):** | **7,256** |
| **Total Water Volume (gal)*:** | **1,384,950** |

| **Trade Name** | **Supplier** | **Purpose** | **Ingredients** | **Chemical Abstract Service Number (CAS #)** | **Maximum Ingredient Concentration in Additive ( by mass)**** | **Maximum Ingredient Concentration in HF Fluid ( by mass)**** |
|---|---|---|---|---|---|---|
| Water | Operator | Carrier | Water | 7732-18-5 | 100.00 | 94.65449 |
| | | | | | | |
| Frac Sand (All Meshes) CWT | BHI | Proppant | Crystalline Silica (Quartz) | 14808-60-7 | 100.00 | 5.30553 |
| | | | | | | |
| FRW-15A | BHI | Friction Reducer | Copolymer of Acrylamide and Sodium Acrylate | 25987-30-8 | 40.00 | 0.01257 |

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
|  |  |  | Hydrotreated Light Distillate | 64742-47-8 | 30.00 | 0.00943 |
|  |  |  | Nonyl Phenol Ethoxylate | 127087-87-0 | 5.00 | 0.00157 |
|  |  |  | Sorbitan Monooleate | 1338-43-8 | 5.00 | 0.00157 |
|  |  |  |  |  |  |  |
| SCW5277 | BHI | Scale Inhibitor | Phosphonate Salt | CBI | 5.00 | 0.00026 |
|  |  |  |  |  |  |  |
| X-Cide 150 | BHI | Biocide | Glutaraldehyde | 111-30-8 | 60.00 | 0.00839 |
|  |  |  | Quaternary Ammonium Compound | 68424-85-1 | 10.00 | 0.00140 |
|  |  |  |  |  |  |  |
| X-Cide 370 | BHI | Biocide | Oxydiethylene Bis(Alkyl* Dimethyl Ammonium Chloride) | 68607-28-3 | 60.00 | 0.00240 |
|  |  |  | Methanol | 67-56-1 | 60.00 | 0.00240 |

* Total Water Volume sources may include fresh water, produced water, and/or recycled water

** Information is based on the maximum potential for concentration and thus the total may be over 100

All component information listed was obtained from the supplier's Material Safety Data Sheets (MSDS). As such, the Operator is not responsible for inaccurate and/or incomplete information. Any questions regarding the content of the MSDS should be directed to the supplier who provided it. The Occupational Safety and Health Administration's (OSHA) regulations govern the criteria

## Marcellus Shale

### Well name: Adamson B

| | |
|---|---|
| **Fracture Date** | **4/27/2012** |
| **State:** | **Pennsylvania** |
| **County:** | **Greene** |
| **API Number:** | **37-059-25643** |
| **Operator Name:** | **EQT PRODUCTION** |
| **Well Name and Number:** | **ADAMSON B** |
| **Longitude:** | **-80.118167** |
| **Latitude:** | **39.968917** |
| **Long/Lat Projection:** | **NAD83** |
| **Production Type:** | **Gas** |
| **True Vertical Depth (TVD):** | **7,996** |
| **Total Water Volume (gal)*:** | **8,659,014** |

| **Trade Name** | **Supplier** | **Purpose** | **Ingredients** | **Chemical Abstract Service Number (CAS #)** | **Maximum Ingredient Concentration in Additive ( by mass)**** | **Maximum Ingredient Concentration in HF Fluid ( by mass)**** |
|---|---|---|---|---|---|---|
| HCl | Halliburton | 15 HCl Acid | Hydrochloric Acid | 7647-01-0 | 28 | 0.0300 |
| HCl | Halliburton | Corrosion Inhibitor | Propargyl Alcohol | 107-19-7 | 10 | 0.0000 |
| HCl | Halliburton | Corrosion Inhibitor | Methanol | 67-56-1 | 60 | 0.0003 |
| FR-66 | Halliburton | Friction Reducer | Hydrotreated light petroleum | 64742-47-8 | 30 | 0.0335 |

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
|  |  |  | distillate |  |  |  |
| BE-9 | Halliburton | Biocide | Tributyl tetradecyl phosphonium chloride | 81741-28-8 | 10 | 0.0047 |
| LP-65 | Halliburton | Scale Inhibitor | Ammonium chloride | 12125-02-9 | 10 | 0.0030 |
| LGC-36 | Halliburton | Gelling Agent | Guar Gum | 9000-30-0 | 30 | 0.0022 |
| LGC-36 | Halliburton | Gelling Agent | Naptha, hydrotreated heavy | 64742-48-9 | 30 | 0.0022 |
| SP Breaker | Halliburton | Oxidizing Breaker | Sodium Persulfate | 7775-27-1 | 100 | 0.0001 |
| GBW-30 | Halliburton | Enzyme Breaker | Hemicellulase Enzyme | 9012-54-8 | 15 | 0.00000 |
| BA-40L | Halliburton | Buffer | Potassium carbonate | 584-08-7 | 60 | 0.01255 |

* Total Water Volume sources may include fresh water, produced water, and/or recycled water

** Information is based on the maximum potential for concentration and thus the total may be over 100

Ingredient information for chemicals subject to 29 CFR 1910.1200(i) and Appendix D are obtained from suppliers Material Safety Data Sheets (MSDS)

## Well name: Currey 1H

| | |
|---|---|
| **Fracture Date** | **4/15/2010** |
| **State:** | **WV** |
| **County:** | **Taylor** |
| **API Number:** | **47-091-01188** |
| **Operator Name:** | **Triana** |
| **Well Name and Number:** | **Currey 1H** |
| **Longitude:** | **-80.14093** |
| **Latitude:** | **39.35** |
| **Long/Lat Projection:** | **NAD83** |
| **Production Type:** | **Gas** |
| **True Vertical Depth (TVD):** | **7,500** |
| **Total Water Volume (gal)*:** | **4,661,580** |

| **Trade Name** | **Supplier** | **Purpose** | **Ingredients** | **Chemical Abstract Service Number (CAS #)** | **Maximum Ingredient Concentration in Additive ( by mass)**** | **Maximum Ingredient Concentration in HF Fluid ( by mass)**** |
|---|---|---|---|---|---|---|
| Water | Seneca | Carrier / Base Fluid | | | 100 | 89.721704 |
| Sand (Proppant) | Halliburton Energy Services | Proppant | Crystalline silica, quartz | 14808-60-7 | 100.00 | 9.55112 |
| 7.5 HCl Acid*** | Halliburton Energy Services | Solvent | Hydrochloric Acid | 7647-01-0 | 15.00 | 0.08076 |
| HAI-OS | Halliburton Energy Services | Corrosion Inhibitor | Propargyl alcohol | 107-19-7 | 10.00 | 0.00005 |
| | | | Methanol | 67-56-1 | 60.00 | 0.00028 |
| GBW-30 | Halliburton Energy Services | Gel Breaker | Carbohydrates | | 95.00 | 0.00001 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | Hemicellulase enzyme | 9012-54-8 | 15.00 | 0.00000 |
| SP | Halliburton Energy Services | Gel Breaker | Sodium persulfate | 7775-27-1 | 100.00 | 0.00000 |
| LGC-36 UC | Halliburton Energy Services | Liquid Gel Concentrate | Guar gum | 9000-30-0 | 60.00 | 0.00120 |
| | | | Naptha, hydrotreated heavy | 64742-48-9 | 60.00 | 0.00120 |
| LP-65 | Halliburton Energy Services | Scale Inhibitor | Amnonium chloride | 12125-02-9 | 10.00 | 0.00490 |
| BE-9M | Halliburton Energy Services | Biocide | Tributyl tetradecyl phosphonium chloride | 81741-28-8 | 10.00 | 0.00490 |
| | | | Methanol | 67-56-1 | 30.00 | 0.01277 |
| FR-66 | Halliburton Energy | Friction Reducer | Hydrotreated light petroleum distillate | 64742-47-8 | 30.00 | 0.02839 |
| | Services | | | | | |
| WG-36 | Halliburton Energy Services | Gelling Agent | Guar gum | 900-30-0 | 100.00 | 0.00014 |

* Total Water Volume sources may include fresh water, produced water, and/or recycled water

** Information is based on the maximum potential for concentration and thus the total may be over 100

Ingredient information for chemicals subject to 29 CFR 1910.1200(i) and Appendix D are obtained from suppliers Material Safety Data Sheets (MSDS)

### Well name: Zogal 2H

| | |
|---|---|
| **Fracture Date** | **5/16/2011** |
| **State:** | **WV** |
| **County:** | **Marion** |
| **API Number:** | **47-049-02146** |
| **Operator Name:** | **XTO Energy** |
| **Well Name and Number:** | **Zogol 2H** |
| **Longitude:** | **-80.34837** |
| **Latitude:** | **39.48734** |
| **Long/Lat Projection:** | **NAD27** |
| **Production Type:** | **Gas** |
| **True Vertical Depth (TVD):** | **7,465** |
| **Total Water Volume (gal)*:** | **3,706,034** |

| **Trade Name** | **Supplier** | **Purpose** | **Ingredients** | **Chemical Abstract Service Number (CAS #)** | **Maximum Ingredient Concentration in Additive ( by mass)**** | **Maximum Ingredient Concentration in HF Fluid ( by mass)**** |
|---|---|---|---|---|---|---|
| Water | | | | 7732-18-5 | 100.00 | 88.746 |
| Sand | | Proppant | Crystaline Silica | 14808-60-7 | 100.00 | 10.691 |
| Biocide EC 6116A | Universal | Biocide | | | | |
| | | | Dibromoacetonitrile | 3252-43-5 | 5.00 | 0.002 |
| | | | 2,2-Dibromo-3-nitrilopropionamide | 10222-01-2 | 30.00 | 0.010 |
| | | | Polyethylene Glycol | 25322- | 60.00 | 0.020 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | 68-3 | | |
| | | | Other - unspecified | | 5.00 | 0.002 |
| Unislik ST 50 | Universal | Friction Reducer | | | | |
| | | | Hydrotreated light distillates | 64742-47-8 | 30.00 | 0.017 |
| | | | Polyacrylamide powder and other | | 70.00 | 0.041 |
| EC 6486A | Universal | Scale Inhibitor | | | | |
| | | | Ethylene glycol | 107-21-1 | 30.00 | 0.007 |
| | | | Other - unspecified | | 70.00 | 0.017 |
| 7.5 HCl Acid | Universal | Cleaning | | | | |
| | | | Hydrogen Chloride | 7647-01-0 | 7.50 | 0.033 |
| | | | Water | 7732-18-5 | 92.50 | 0.413 |

* Total Water Volume sources may include fresh water, produced water, and/or recycled water

** Information is based on the maximum potential for concentration and thus the total may be over 100

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## Appendix II – Employment in Hydraulic Fracturing Industry[71]

| Occupation | 2012 | | Projected 2022 | | Employment change 2012-2022 | |
|---|---|---|---|---|---|---|
| Title | Employment (in thousands) | Percent of Industry | Employment (in thousands) | Percent of Industry | Number (in thousands) | Percent |
| Total, all occupations | 186.8 | 100 | 220.7 | 100 | 33.9 | 18.1 |
| Chief executives | 0.8 | 0.4 | 0.8 | 0.4 | 0.1 | 9.6 |
| General and operations managers | 5.6 | 3 | 6.4 | 2.9 | 0.9 | 15.4 |
| Marketing managers | 0.6 | 0.3 | 0.6 | 0.3 | 0.1 | 15.4 |
| Sales managers | 0.5 | 0.3 | 0.6 | 0.3 | 0.1 | 15.4 |
| Public relations and fundraising managers | 0.2 | 0.1 | 0.2 | 0.1 | 0 | 15.4 |
| Administrative services managers | 0.6 | 0.3 | 0.7 | 0.3 | 0.1 | 15.4 |
| Computer and information systems managers | 0.6 | 0.3 | 0.7 | 0.3 | 0.1 | 15.4 |
| Financial managers | 2.6 | 1.4 | 3 | 1.3 | 0.4 | 15.4 |
| Industrial production managers | 1.5 | 0.8 | 1.7 | 0.8 | 0.2 | 15.4 |
| Purchasing managers | 0.5 | 0.3 | 0.6 | 0.3 | 0.1 | 15.4 |
| Transportation, storage, and distribution managers | 0.4 | 0.2 | 0.4 | 0.2 | 0.1 | 15.4 |
| Human resources managers | 0.6 | 0.3 | 0.7 | 0.3 | 0.1 | 15.4 |
| Training and development managers | 0.1 | 0 | 0.1 | 0 | 0 | 15.4 |
| Construction managers | 0.3 | 0.2 | 0.3 | 0.2 | 0 | 16 |
| Architectural and engineering managers | 7.2 | 3.8 | 8.3 | 3.7 | 1.1 | 15.4 |
| Natural sciences managers | 0.3 | 0.1 | 0.3 | 0.1 | 0 | 15.4 |
| Property, real estate, and community association managers | 1.5 | 0.8 | 1.7 | 0.8 | 0.2 | 15.4 |
| Managers, all other | 1.1 | 0.6 | 1.2 | 0.6 | 0.2 | 15.4 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Purchasing agents, except wholesale, retail, and farm products | 0.5 | 0.3 | 0.6 | 0.3 | 0.1 | 15.4 |
| Compliance officers | 0.9 | 0.5 | 1.1 | 0.5 | 0.1 | 15.4 |
| Human resources specialists | 0.9 | 0.5 | 1 | 0.4 | 0.1 | 7.3 |
| Logisticians | 0.7 | 0.4 | 0.9 | 0.4 | 0.2 | 34.5 |
| Management analysts | 1.2 | 0.6 | 1.3 | 0.6 | 0.2 | 15.4 |
| Compensation, benefits, and job analysis specialists | 0.1 | 0.1 | 0.2 | 0.1 | 0 | 9.6 |
| Training and development specialists | 0.1 | 0.1 | 0.2 | 0.1 | 0 | 15.4 |
| Market research analysts and marketing specialists | 0.4 | 0.2 | 0.6 | 0.3 | 0.1 | 33.3 |
| Business operations specialists, all other | 5 | 2.7 | 5.7 | 2.6 | 0.8 | 15.4 |
| Accountants and auditors | 7.2 | 3.8 | 8.3 | 3.8 | 1.1 | 15.4 |
| Financial analysts | 1.7 | 0.9 | 2 | 0.9 | 0.3 | 15.4 |
| Financial specialists, all other | 0.2 | 0.1 | 0.3 | 0.1 | 0 | 15.4 |
| Computer systems analysts | 3.1 | 1.7 | 4 | 1.8 | 0.8 | 26.9 |
| Information security analysts | 0.1 | 0.1 | 0.2 | 0.1 | 0 | 32.7 |
| Computer programmers | 0.3 | 0.2 | 0.3 | 0.2 | 0 | 3.8 |
| Software developers, applications | 0.1 | 0 | 0.1 | 0 | 0 | 15.4 |
| Web developers | 0.1 | 0 | 0.1 | 0 | 0 | 15.4 |
| Database administrators | 0.2 | 0.1 | 0.2 | 0.1 | 0 | 9.6 |
| Network and computer systems administrators | 2.1 | 1.1 | 2.4 | 1.1 | 0.3 | 15.4 |
| Computer network architects | 0.1 | 0 | 0.1 | 0 | 0 | 15.4 |
| Computer user support specialists | 0.5 | 0.3 | 0.6 | 0.3 | 0.1 | 15.4 |
| Computer network support specialists | 0.5 | 0.3 | 0.5 | 0.2 | 0 | 4.4 |
| Cartographers and photogrammetrists | 0.1 | 0 | 0.1 | 0 | 0 | 15.4 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Surveyors | 0.2 | 0.1 | 0.2 | 0.1 | 0 | 15.4 |
| Chemical engineers | 0.6 | 0.3 | 0.7 | 0.3 | 0.1 | 15.4 |
| Civil engineers | 0.2 | 0.1 | 0.3 | 0.1 | 0 | 15.4 |
| Electrical engineers | 0.2 | 0.1 | 0.3 | 0.1 | 0 | 15.4 |
| Environmental engineers | 0.6 | 0.3 | 0.7 | 0.3 | 0.1 | 15.4 |
| Health and safety engineers, except mining safety engineers and inspectors | 0.2 | 0.1 | 0.3 | 0.1 | 0 | 15.4 |
| Industrial engineers | 3 | 1.6 | 3.5 | 1.6 | 0.5 | 15.4 |
| Materials engineers | 0.1 | 0 | 0.1 | 0 | 0 | 15.4 |
| Mechanical engineers | 0.4 | 0.2 | 0.5 | 0.2 | 0.1 | 15.4 |
| Mining and geological engineers, including mining safety engineers | 0.4 | 0.2 | 0.4 | 0.2 | 0.1 | 15.4 |
| Petroleum engineers | 20.5 | 11 | 28.5 | 12.9 | 8 | 39.1 |
| Engineers, all other | 1.2 | 0.6 | 1.4 | 0.6 | 0.2 | 15.4 |
| Electrical and electronics engineering technicians | 0.3 | 0.1 | 0.3 | 0.1 | 0 | 15.4 |
| Environmental engineering technicians | 0.5 | 0.3 | 0.6 | 0.3 | 0.1 | 15.4 |
| Industrial engineering technicians | 0.6 | 0.3 | 0.6 | 0.3 | 0.1 | 15.4 |
| Mechanical engineering technicians | 0.1 | 0 | 0.1 | 0 | 0 | 15.4 |
| Engineering technicians, except drafters, all other | 1.9 | 1 | 2.2 | 1 | 0.3 | 15.4 |
| Surveying and mapping technicians | 0.4 | 0.2 | 0.5 | 0.2 | 0.1 | 15.4 |
| Physicists | 0.3 | 0.2 | 0.4 | 0.2 | 0.1 | 15.4 |
| Environmental scientists and specialists, including health | 0.7 | 0.4 | 0.9 | 0.4 | 0.1 | 15.4 |
| Geoscientists, except hydrologists and geographers | 9.9 | 5.3 | 11.4 | 5.2 | 1.5 | 15.4 |
| Economists | 0.2 | 0.1 | 0.3 | 0.1 | 0 | 15.4 |
| Chemical technicians | 0.1 | 0 | 0.1 | 0 | 0 | 15.4 |

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
| Geological and petroleum technicians | 3 | 1.6 | 3.5 | 1.6 | 0.5 | 15.4 |
| Lawyers | 1.3 | 0.7 | 1.5 | 0.7 | 0.2 | 15.4 |
| Paralegals and legal assistants | 0.3 | 0.1 | 0.3 | 0.1 | 0 | 15.4 |
| Title examiners, abstractors, and searchers | 0.8 | 0.4 | 0.9 | 0.4 | 0.1 | 15.4 |
| Legal support workers, all other | 0.1 | 0.1 | 0.1 | 0.1 | 0 | 15.4 |
| Public relations specialists | 0.1 | 0.1 | 0.1 | 0.1 | 0 | 15.4 |
| Occupational health and safety specialists | 0.7 | 0.4 | 0.8 | 0.4 | 0.1 | 15.4 |
| Occupational health and safety technicians | 0.1 | 0 | 0.1 | 0 | 0 | 15.4 |
| Janitors and cleaners, except maids and housekeeping cleaners | 0.3 | 0.1 | 0.3 | 0.1 | 0 | 15.4 |
| First-line supervisors of non-retail sales workers | 0.2 | 0.1 | 0.2 | 0.1 | 0 | 15.4 |
| Sales representatives, services, all other | 0.3 | 0.2 | 0.4 | 0.2 | 0.1 | 15.4 |
| Sales representatives, wholesale and manufacturing, technical and scientific products | 0.3 | 0.2 | 0.4 | 0.2 | 0 | 15.4 |
| Sales representatives, wholesale and manufacturing, except technical and scientific products | 0.5 | 0.3 | 0.6 | 0.3 | 0.1 | 15.4 |
| Real estate sales agents | 0.8 | 0.4 | 0.9 | 0.4 | 0.1 | 15.4 |
| First-line supervisors of office and administrative support workers | 1.5 | 0.8 | 1.8 | 0.8 | 0.2 | 15.4 |
| Billing and posting clerks | 0.1 | 0.1 | 0.1 | 0.1 | 0 | 15.4 |
| Bookkeeping, accounting, and auditing clerks | 4 | 2.2 | 4.6 | 2.1 | 0.6 | 15.4 |
| Payroll and timekeeping clerks | 0.2 | 0.1 | 0.2 | 0.1 | 0 | 15.4 |
| Customer service representatives | 0.1 | 0 | 0.1 | 0 | 0 | 15.4 |

| | | | | | | |
|---|---|---|---|---|---|---|
| File clerks | 0.3 | 0.2 | 0.3 | 0.1 | 0 | -3.8 |
| Order clerks | 0.2 | 0.1 | 0.2 | 0.1 | 0 | 3.8 |
| Human resources assistants, except payroll and timekeeping | 0.1 | 0 | 0.1 | 0 | 0 | 3.8 |
| Receptionists and information clerks | 0.6 | 0.3 | 0.6 | 0.3 | 0 | 3.8 |
| Information and record clerks, all other | 0.7 | 0.4 | 0.7 | 0.3 | 0 | 3.8 |
| Production, planning, and expediting clerks | 0.8 | 0.4 | 1 | 0.4 | 0.1 | 15.4 |
| Stock clerks and order fillers | 0.2 | 0.1 | 0.2 | 0.1 | 0 | 3.8 |
| Weighers, measurers, checkers, and samplers, recordkeeping | 0.1 | 0 | 0.1 | 0 | 0 | 15.4 |
| Executive secretaries and executive administrative assistants | 4 | 2.1 | 4.1 | 1.9 | 0.1 | 3.2 |
| Secretaries and administrative assistants, except legal, medical, and executive | 5 | 2.7 | 6.1 | 2.7 | 1.1 | 21.7 |
| Data entry keyers | 0.1 | 0.1 | 0.1 | 0 | 0 | -25 |
| Office clerks, general | 3.2 | 1.7 | 3.5 | 1.6 | 0.3 | 9.6 |
| Office and administrative support workers, all other | 0.2 | 0.1 | 0.2 | 0.1 | 0 | 9.6 |
| First-line supervisors of construction trades and extraction workers | 4.7 | 2.5 | 5.6 | 2.5 | 0.9 | 18.8 |
| Construction laborers | 0.2 | 0.1 | 0.2 | 0.1 | 0 | 15.4 |
| Operating engineers and other construction equipment operators | 0.4 | 0.2 | 0.5 | 0.2 | 0.1 | 15.4 |
| Electricians | 0.4 | 0.2 | 0.4 | 0.2 | 0.1 | 15.4 |
| Plumbers, pipefitters, and steamfitters | 0.1 | 0 | 0.1 | 0 | 0 | 15.4 |
| Derrick operators, oil and gas | 2.6 | 1.4 | 3 | 1.4 | 0.4 | 15.4 |
| Rotary drill operators, oil and gas | 4.7 | 2.5 | 5.5 | 2.5 | 0.8 | 16 |
| Service unit operators, oil, gas, and | 6 | 3.2 | 6.9 | 3.1 | 0.9 | 15.4 |

| | | | | | | |
|---|---|---|---|---|---|---|
| mining | | | | | | |
| Earth drillers, except oil and gas | 0.1 | 0 | 0.1 | 0 | 0 | 15.4 |
| Roustabouts, oil and gas | 8.5 | 4.5 | 9.8 | 4.4 | 1.3 | 15.4 |
| Helpers--extraction workers | 1.1 | 0.6 | 1.3 | 0.6 | 0.2 | 15.4 |
| Extraction workers, all other | 0.3 | 0.1 | 0.3 | 0.1 | 0 | 15.4 |
| First-line supervisors of mechanics, installers, and repairers | 0.7 | 0.4 | 0.8 | 0.4 | 0.1 | 15.4 |
| Electrical and electronics repairers, commercial and industrial equipment | 0.1 | 0.1 | 0.1 | 0.1 | 0 | 21.1 |
| Bus and truck mechanics and diesel engine specialists | 0.1 | 0.1 | 0.1 | 0.1 | 0 | 15.4 |
| Mobile heavy equipment mechanics, except engines | 0.1 | 0.1 | 0.2 | 0.1 | 0 | 15.4 |
| Control and valve installers and repairers, except mechanical door | 0.5 | 0.2 | 0.5 | 0.2 | 0.1 | 15.4 |
| Industrial machinery mechanics | 1.6 | 0.9 | 2.3 | 1 | 0.6 | 38.4 |
| Maintenance workers, machinery | 0.2 | 0.1 | 0.3 | 0.1 | 0.1 | 26.9 |
| Maintenance and repair workers, general | 1.1 | 0.6 | 1.3 | 0.6 | 0.2 | 15.4 |
| Riggers | 0.1 | 0.1 | 0.2 | 0.1 | 0 | 26.9 |
| First-line supervisors of production and operating workers | 2.1 | 1.1 | 2.4 | 1.1 | 0.3 | 15.4 |
| Drilling and boring machine tool setters, operators, and tenders, metal and plastic | 0.1 | 0 | 0.1 | 0 | 0 | -7.7 |
| Machinists | 0.1 | 0.1 | 0.2 | 0.1 | 0 | 26.9 |
| Welders, cutters, solderers, and brazers | 0.5 | 0.3 | 0.6 | 0.3 | 0.1 | 15.4 |
| Power plant operators | 0.1 | 0.1 | 0.1 | 0.1 | 0 | 15.4 |
| Gas plant operators | 1.3 | 0.7 | 1.4 | 0.7 | 0.2 | 15.4 |
| Petroleum pump system operators, refinery operators, and gaugers | 5.8 | 3.1 | 6.7 | 3 | 0.9 | 15.4 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Inspectors, testers, sorters, samplers, and weighers | 0.5 | 0.2 | 0.5 | 0.2 | 0.1 | 15.4 |
| Production workers, all other | 1.4 | 0.8 | 1.7 | 0.7 | 0.2 | 15.4 |
| First-line supervisors of helpers, laborers, and material movers, hand | 0.3 | 0.2 | 0.3 | 0.1 | 0 | 15.4 |
| First-line supervisors of transportation and material-moving machine and vehicle operators | 0.9 | 0.5 | 1.1 | 0.5 | 0.1 | 15.4 |
| Commercial pilots | 0.2 | 0.1 | 0.2 | 0.1 | 0 | 15.4 |
| Heavy and tractor-trailer truck drivers | 1.1 | 0.6 | 1.2 | 0.6 | 0.2 | 15.4 |
| Laborers and freight, stock, and material movers, hand | 0.7 | 0.4 | 0.8 | 0.4 | 0.1 | 15.4 |
| Gas compressor and gas pumping station operators | 0.8 | 0.4 | 0.9 | 0.4 | 0.1 | 15.4 |
| Pump operators, except wellhead pumpers | 2 | 1.1 | 2.3 | 1.1 | 0.3 | 15.4 |
| Wellhead pumpers | 9.1 | 4.9 | 10.5 | 4.7 | 1.4 | 15.4 |

## Appendix III – Severance Tax for Different States[14]

| State | Type of Tax | Description of Tax Rates |
|---|---|---|
| Alabama | Oil and Gas Privilege Tax on Production | 8 percent of gross value at point of production |
| | | 4 percent of gross value at point of incremental production for enhanced recovery projects |
| | | 4 percent if oil wells produce 25 barrels or less per day or if gas wells produce 200,000 cubic feet or less gas per day |
| | | 6 percent of gross value at point of production for certain on-shore and off-shore wells. |
| | | 50 percent rate reduction for wells permitted by the oil and gas board on or after July 1, 1996 and before July 1, 2002 for 5 years from initial production, except for replacement wells for which the initial permit was dated before July 1, 1996. |
| Alaska | Petroleum Profits Tax (PPT) | Ranges from 25 percent to 50 percent depending on net value of oil and gas, which is the value at point of production minus certain lease expenditures |
| | | 22.5 percent net value at wellhead |
| | | There is an additional surcharge for each dollar when net value exceeds $40 per barrel. This cannot exceed 25 percent of the monthly production tax value of taxable oil and gas. |
| | | Conservation surcharge of 4 cents per barrel and an additional 1 cent per barrel if there is less than $50 million in the Hazardous Release Fund |
| Arizona | Severance Tax | 3.125 percent for oil and gas production and nonmetal mining |
| Arkansas | Oil and Gas Conservation Tax | 0.3 of $0.01 cent per MCF for natural gas |
| | | Four percent to five percent depending on production levels for crude oil |
| California | Oil and Gas Production Assessment | Rate determined annually by Department of Conservation |
| Colorado | Severance Tax | Two to five percent based on gross income for oil, gas, carbon dioxide and coalbed methane |
| | | Four percent of gross proceeds on production exceeding 15,000 tons per day for oil shale |
| | Oil and Gas Conservation Levy | Maximum 1.5 mills/$1 of market value at wellhead |

| | | |
|---|---|---|
| Florida | Oil, Gas and Sulfur Production Tax | Five percent of gross value for small well oil |
| | | Eight percent of gross value for all other and an additional 12.5 percent for escaped oil |
| | | For gas, the gas base rate times the gas base adjustment rate each fiscal yea |
| Idaho | Oil and Gas Production Tax | Maximum of five mills/bbl. of oil and five mills/50,000 cubic feet of gas |
| | Additional Oil and Gas Production Tax | Two percent of market value at site of production |
| Indiana | Petroleum Production Tax | One percent of value or $0.24 per barrel for oil, or $0.03 per 1,000 cubic feet of gas (whichever is greater) |
| Kansas | Severance Tax | Eight percent of gross value of oil and gas, less property tax credit of 3.67 percent |
| | Oil and Gas Conservation Tax | 91 mills/bbl crude oil or petroleum marketed or used each month |
| | | 12.9 mills/1,000 cubic feet of gas sold or marketed each month |
| Kentucky | Oil Production Tax | 4.5 percent of market value |
| | Natural Resource Severance Tax | 4.5 percent of gross value, less transportation expenses |
| Louisiana | Natural Resources Severance Tax | Varies according to substance |
| | Oil Field Restoration Fee | Varies according to type of well and production |
| Michigan | Gas and Oil Severance Tax | Five percent for gas |
| | | 6.6 percent for oil |
| | | Four percent (oil from stripper wells and marginal properties) of gross cash market value of the total production |
| | | Maximum additional fee of 1 percent gross cash market value on all oil and gas produced in state in previous year |
| Mississippi | Oil and Gas Severance Tax | Six percent of the value at point of gas production |
| | | Three percent of gross value of occluded natural gas from coal seams at point of production for the well's first five years |
| | | Maximum 35 mills/bbl. oil or four mills/1,000 cubic feet of gas (Oil and Gas Board maintenance tax) |
| | | Six percent of value at the point of oil production |
| | | Three percent of value at production when enhanced oil recovery is used |

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| Montana | Oil or Gas Conservation Tax | Maximum of 0.3 percent on the market value of each barrel of crude petroleum oil or 10,000 cubic feet of natural gas produced, saved and marketed or stored within or exported from the state |
|  | Oil or Natural Gas Production Tax | Varies from 0.5 percent to 14.8 percent according to the well and type of production |
| Nebraska | Oil and Gas Severance Tax | Three percent of value of nonstripper oil and natural gas |
|  | Oil and Gas Conservation Tax | Two percent of value of stripper oil. Maximum of 15 mills/$1 of value at wellhead |
| Nevada | Oil and Gas Conservation Tax | $50/mills/bbl of oil and 50 mills/50,000 cubic feet of gas |
| New Hampshire | Refined Petroleum Products Tax | 0.1 percent of fair market value |
|  | Excavation Tax | $0.02 per cubic yard of earth excavated |
| New Mexico | Oil and Gas Severance Tax | 3.75 percent of value of oil, other liquid hydrocarbons, natural gas and carbon dioxide |
|  | Oil and Gas Emergency School Tax | • 3.15 percent of value of oil, other liquid hydrocarbons and carbon dioxide; Four percent of the value of natural gas |
|  | Natural Gas Processor's Tax | $0.0220/mmBtu tax on the volume |
|  | Oil and Gas Ad Valorem Production Tax | Based on property tax in the district of production |
|  | Oil and Gas Conservation Tax | 0.19 percent of value |
| North Carolina | Oil and Gas Conservation Tax | Maximum of five mills/barrel of oil and 0.5 mill/1,000 cubic feet of gas |
| North Dakota | Oil Gross Production Tax | Five percent of gross value at the well |
|  | Gas Gross Production Tax | $0.04 per 1,000 cubic feet of gas produced. The rate is subject to a gas rate adjustment each fiscal year. |
|  | Oil Extraction Tax | 6.5 percent of gross value at the well. Exceptions exist for certain production volumes and incentives for enhanced recovery projects. |
| Ohio | Resource Severance Tax | $0.10/bbl of oil |
|  |  | $0.025/1,000 cubic feet of natural gas |
| Oklahoma | Oil, Gas and Mineral Gross Production Tax and Petroleum Excise Tax | Seven percent if greater than $2.10 mcf; four percent if greater than $1.75 mcf but less than $2.10 mcf; and one percent if less than $1.75 mcf natural gas and casing head gas (a byproduct of natural gas extraction), and 0.95 percent levied on crude oil, casing head gas and natural gas. |

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| | | Oil Gross Production Tax is variable based on the average price of Oklahoma oil. The tax rate is seven percent if average price is equal to or exceeds \$17/bbl; four percent if the average price is less than \$17/bbl but equal to or exceeds \$14/bbl; and one percent if the average price is less than \$14/bbl. |
| Oregon | Oil and Gas Production Tax | Six percent of gross value at well |
| South Dakota | Energy Minerals Severance Tax | 4.5 percent of taxable value of all energy minerals |
| | Conservation Tax | 2.4 mills of taxable value of all energy minerals |
| Tennessee | Oil and Gas Severance Tax | Three percent of sales price |
| Texas | Natural Gas Production Tax | 7.5 percent of market value of gas |
| | | Condensate Production Tax is 4.6 percent of market value of gas |
| | Oil-Field Cleanup Regulatory Fees | 5/8 of \$0.01/barrel |
| | | 1/15 of \$0.01/1,000 cubic feet of gas |
| Utah | Oil and Gas Severance Tax | Three percent of value for the first \$13 per barrel of oil and five percent if the value is \$13.01 or higher |
| | | Three percent of value for the first \$1.50/mcf and five percent if the value is \$1.51 or higher |
| | | Four percent of taxable value of natural gas liquids |
| | Oil and Gas Conservation Fee | 0.002 percent of market value at the wellhead |
| West Virginia | Natural Resource Severance Taxes | Five percent of gross value for natural gas; ten percent of net tax is distributed to local governments |
| | | Five percent of gross value for oil; ten percent of net tax is distributed to local governments |
| | | Additional tax for workers' compensation debt reduction rate of \$0.047/mcf of natural gas produced |
| Wisconsin | Oil and Gas Severance Tax | Seven percent of market value of oil or gas at the mouth of the well |
| Wyoming | Severance Taxes | Six percent on crude oil, lease condensate or natural gas |
| | | Four percent for stripper oil |

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