

Ohio River Valley Water Sanitation Commission



Hydraulic Fracturing in the Ohio River Basin

October 2015

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Commonly Used terms in the Oil and Gas Industry

coalbed methane (CBM) - Coalbed methane is a form of natural gas generated by and extracted from coal beds. In recent decades it has become an important source of energy in the United States and other countries.

continuous oil & gas accumulations - Commonly are regional in extent, have diffuse boundaries, and are not buoyant on a column of water. Continuous accumulations have very low matrix permeabilities, do not have obvious seals and traps, are in close proximity to source rocks, are abnormally pressured, and have relatively low recovery factors. Included in the category of continuous accumulations are hydrocarbons that occur in tight sand reservoirs, shale reservoirs, basin-centered reservoirs, fractured reservoirs, and coal beds.

continuous oil accumulation - A "continuous" or "unconventional" oil accumulation means that the oil resource is dispersed throughout a geologic formation rather than existing as discrete, localized occurrences, such as those in conventional accumulations. Unconventional resources often require special technical drilling and recovery methods.

conventional oil & gas accumulations - Are discrete accumulations with well-defined hydrocarbon-water contacts, where the hydrocarbons are buoyant on a column of water. Conventional accumulations commonly have relatively high matrix permeabilities, have obvious seals and traps, and have relatively high recovery factors.

conventional well – State of Pennsylvania’s terminology for a vertical well (vs. unconventional)

crude oil - A mixture of liquid hydrocarbons that exists in natural underground reservoirs as distinguished from refined oils manufactured from it. Does not include liquid hydrocarbons produced from tar sand, gilsonite, oil shale, or coal.

discovered - Hydrocarbons whose location and quantity are known or estimated from specific geologic evidence are discovered resources. Discovered resources include known resources, unproved reserves, and proved reserves depending upon economic, technical, contractual, or regulatory criteria.

economically recoverable resources - Are that part of the assessed technically recoverable resource for which the costs of finding, development, and production, including a return to capital, can be recovered by production revenues at a given price.

enhanced recovery well – State of Ohio’s terminology for a horizontal well that is hydraulically fracked.

flowback water – the wastewater that flows back to the surface during the first 30 days after initial pressure has been relieved. The oil and gas industry refer to this as low salinity flowback (<50,000 mg/L TDS)

formation - A body of rock strata, of intermediate rank in the hierarchy of lithostratigraphic units, which is unified with respect to adjacent strata by consisting dominantly of a certain lithologic type, or by possessing other unifying lithologic features.

fossil fuel - A general term for any hydrocarbon that may be used for fuel: chiefly oil, natural gas, and coal.

fracking - See "hydraulic fracturing"

gas - Also referred to as natural gas, is a naturally occurring hydrocarbon gas mixture consisting primarily of methane with up to 20 percent of other hydrocarbons as well as impurities in varying amounts.

Gas-rich shale is the source rock for many natural gas resources, but, until now, has not been a focus for production. Horizontal drilling and hydraulic fracturing have made shale gas an economically viable alternative to conventional gas resources.

hydraulic fracturing - Also referred to as hydrofracking, hydrofracturing, and fracking, is a well development process that involves injecting water under high pressure into a bedrock formation via the well. This is intended to increase the size and extent of existing bedrock fractures.

natural gas - See also "gas." Hydrocarbons that exist as a gas or vapor at ordinary pressure and temperature. Methane is the most important, but ethane, propane, and others may be present. Common impurities include nitrogen, carbon dioxide, and hydrogen sulfide. Natural gas may occur alone or associated with oil.

natural gas basin - A depressed area in the Earth's crust, of tectonic origin, in which sediments have accumulated and natural gas has been generated and/or accumulated, and/or migrated.

natural gas field - A region or area that possesses or is characterized by natural gas.

natural gas liquids - Those hydrocarbons in natural gas that are separated from the gas as liquids through the process of absorption, condensation, adsorption, or other methods in gas processing or cycling plants. Natural gas liquids include natural gas plant liquids (primarily ethane, propane, butane, and isobutane) and lease condensate (primarily pentanes produced from natural gas at lease separators and field facilities).

natural gas play - The active exploration or leasing of land for natural gas.

oil - A naturally occurring complex liquid hydrocarbon, which after distillation and removal of impurities yields a range of combustible fuels, petrochemicals, and lubricants. Crude oil refers to oil as it emerges from a well but before refining or distillation.

oil & gas basin - A region in which oil and gas of known or possible economic value occurs within a basinal structure.

produced waters - Produced water is a term used to describe wastewater that is produced along with oil and gas after the initial flowback has ceased, can occur throughout the life of the well, see flowback waters. The oil and gas refer to produced water as high salinity wastewater (>50,000 mg/L TDS)

proved reserves - Those quantities of petroleum which, by analysis of geological and engineering data, can be estimated with reasonable certainty to be commercially recoverable, from a given date forward, from known reservoirs and under current economic conditions, operating methods, and government regulations.

recoverability - In reference to accessible coal resources, the condition of being physically, technologically, and economically minable. Recovery rates and recovery factors may be determined or estimated for coal resources without certain knowledge of their economic minability; therefore, the availability of recovery rates or factors does not predict recoverability. A measure of mining or extraction efficiency.

reserve growth - Reserve growth is the increase in estimated volumes of oil and natural gas that can be recovered from existing fields and reservoirs through time. Most reserve growth results from delineation of new reservoirs, field extensions, or improved recovery techniques thereby improving efficiency, and recalculation of reserves due to changing economic and operating conditions.

reserves - are those quantities of petroleum anticipated to be commercially recoverable by application of development projects to known accumulations from a given date forward under defined conditions. Reserves must further satisfy four criteria: they must be discovered, recoverable, commercial, and remaining (as of the evaluation date) based on the development project(s) applied.

reserves, possible - Those unproved reserves which analysis of geological and engineering data suggests are less likely to be recoverable than probable reserves (probability 10-50%) (SPE).

reserves, probable - Those unproved reserves which analysis of geological and engineering data suggests are more likely than not (>50% probability) to be recoverable (SPE).

reserves, proved - Those quantities of petroleum which, by analysis of geological and engineering data, can be estimated with reasonable certainty (90% probability) to be commercially recoverable, from a given date forward, from known reservoirs and under current economic conditions, operating methods, and government regulations (SPE).

reservoir - A subsurface, porous, permeable rock body in which oil or gas or both have accumulated.

shale gas - Shale gas refers to natural gas that can be generated and trapped within shale units.

spud date - A term used in Pennsylvania as the date when drilling was initiated

shale oil - Shale oil refers to liquid petroleum that can be generated and trapped within shale units.

source rock - Rocks containing relatively large amounts of organic matter that is transformed into hydrocarbons.

technically recoverable resource (TRR) – Technically recoverable reserves consist of "proved reserves" and "unproved resources." Proved reserves of crude oil and natural gas are the estimated volumes expected to be produced, with reasonable certainty, under existing economic and operating conditions. Unproved resources are additional volumes estimated to be technically recoverable without consideration of economics or operating conditions, based on the application of current technology

tight gas - Is natural gas trapped in a highly mixed mineralogy sandstone, shale, or limestone formations which has very low permeability and porosity. While conventional natural gas accumulations, once drilled, contain gas that can usually be extracted quite readily and easily, a great deal more effort, including hydrofracturing, has to be put into extracting gas from a tight formation.

unconventional well – State of Pennsylvania's terminology for a horizontal well that is hydraulically fracked.

unproved reserves - Unproved resources are additional volumes estimated to be technically recoverable without consideration of economics or operating conditions, based on the application of current technology. As wells are drilled and field equipment is installed, unproved resources become proved reserves and, ultimately, production.

undiscovered - Resources postulated, on the basis of geologic knowledge and theory, to exist outside of known fields or accumulations. Included also are resources from undiscovered pools within known fields to the extent that they occur within separate plays.



Introduction

In 2004, an oil & gas company drilled the first horizontal well into Marcellus shale in Pennsylvania. The well showed great promise. Since then the industry has flourished. There are now, over 6,000 horizontal wells in the Ohio River basin. USGS estimates that there is more undiscovered technically recoverable natural gas in the Appalachian Basin (148 TCFG) (Figure 1) than any other onshore basin in the country (second most is Texas with 131 TCFG). There is enough natural gas in the U.S. to supply the country for about 100 years. Annual production rates continue to climb and are at a new high of 23 trillion cubic feet (tcf) and will rise 47% by the year 2040. The gas is trapped deep below the surface of the Earth, about 7,000 – 12,000 feet deep, and a combination of horizontal drilling and hydraulic fracturing, from now on referred to as “fracking,” is needed to recover the gas. Fracking has been a topic of concern due to its potential negative effects on the environment. Fracking can leak chemicals into surface and ground water sources, the disposal methods of the frac fluids must be addressed and the volume of water needed to frac a well is great. Much of the Ohio River basin is underlain by shale plays (Figure 2) and there exists even more potential for drilling to occur. There exists a potential of over 104,000 horizontal wells will need to be drilled in order to extract the natural gas from the Marcellus and Utica Shale only. With the proximity of the shale gas plays to the Midwest and eastern region of the U.S. and infrastructure already in place, the demand for this natural gas will be high and economically cheap to produce. To better understand the water use demand and repercussions of fracking we must know the history of the drilling that has already occurred, an inventory of already drilled wells, current water use by the sector, and potential gas reserves in the Ohio River basin.

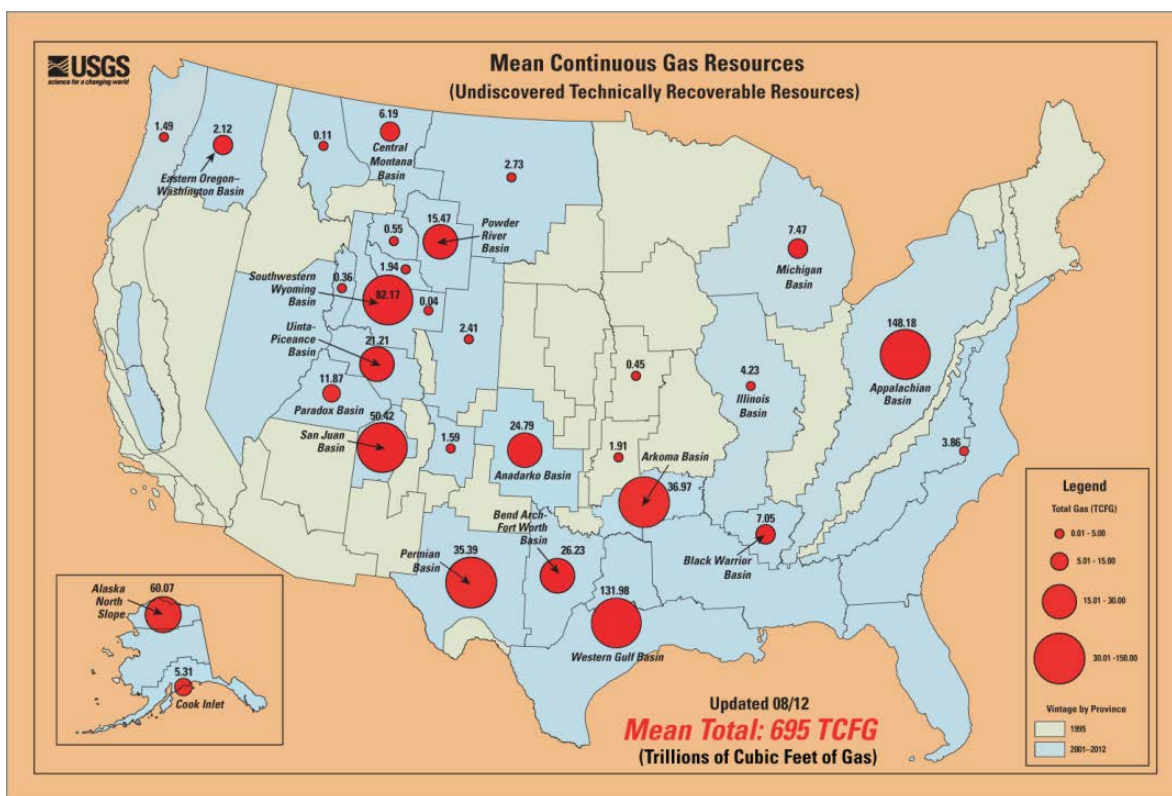


Figure 1: USGS natural gas estimates

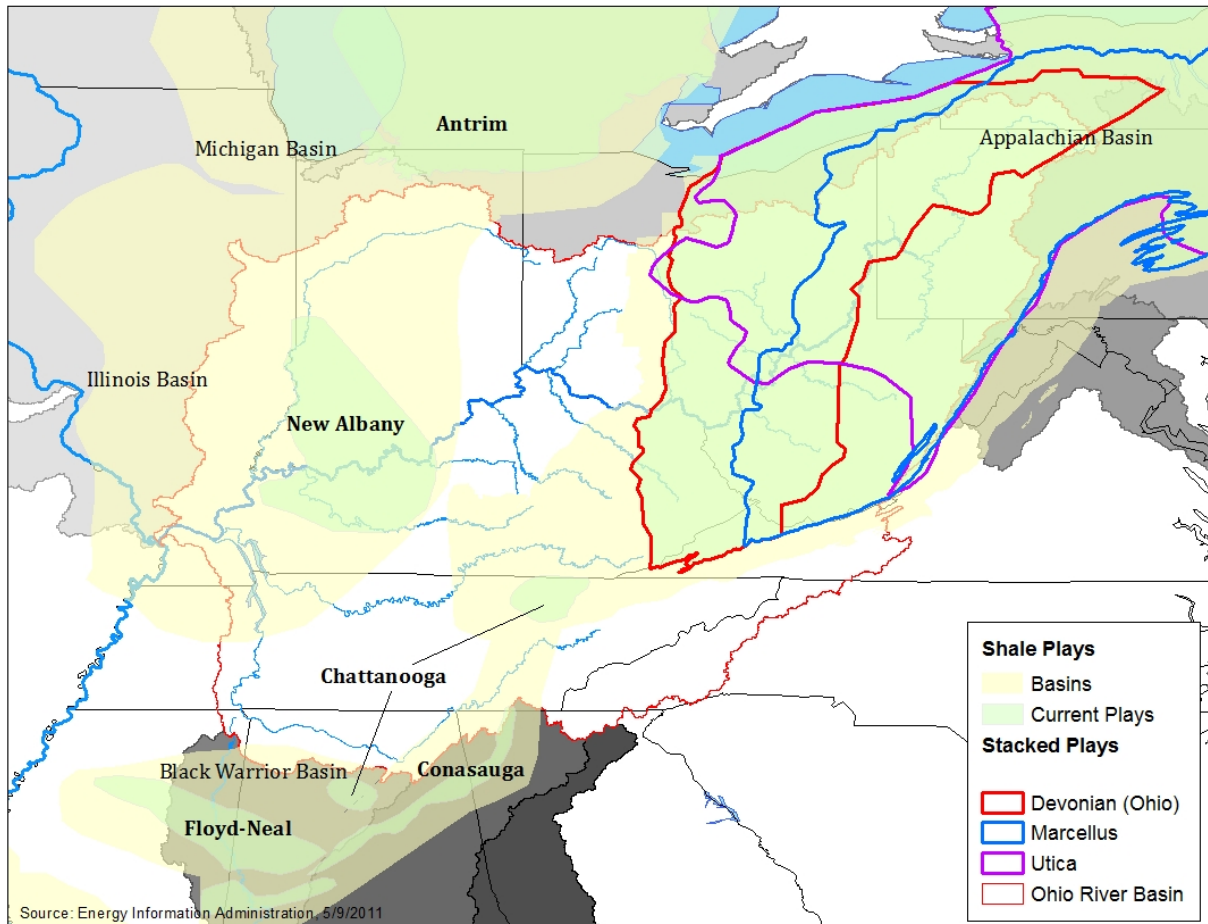
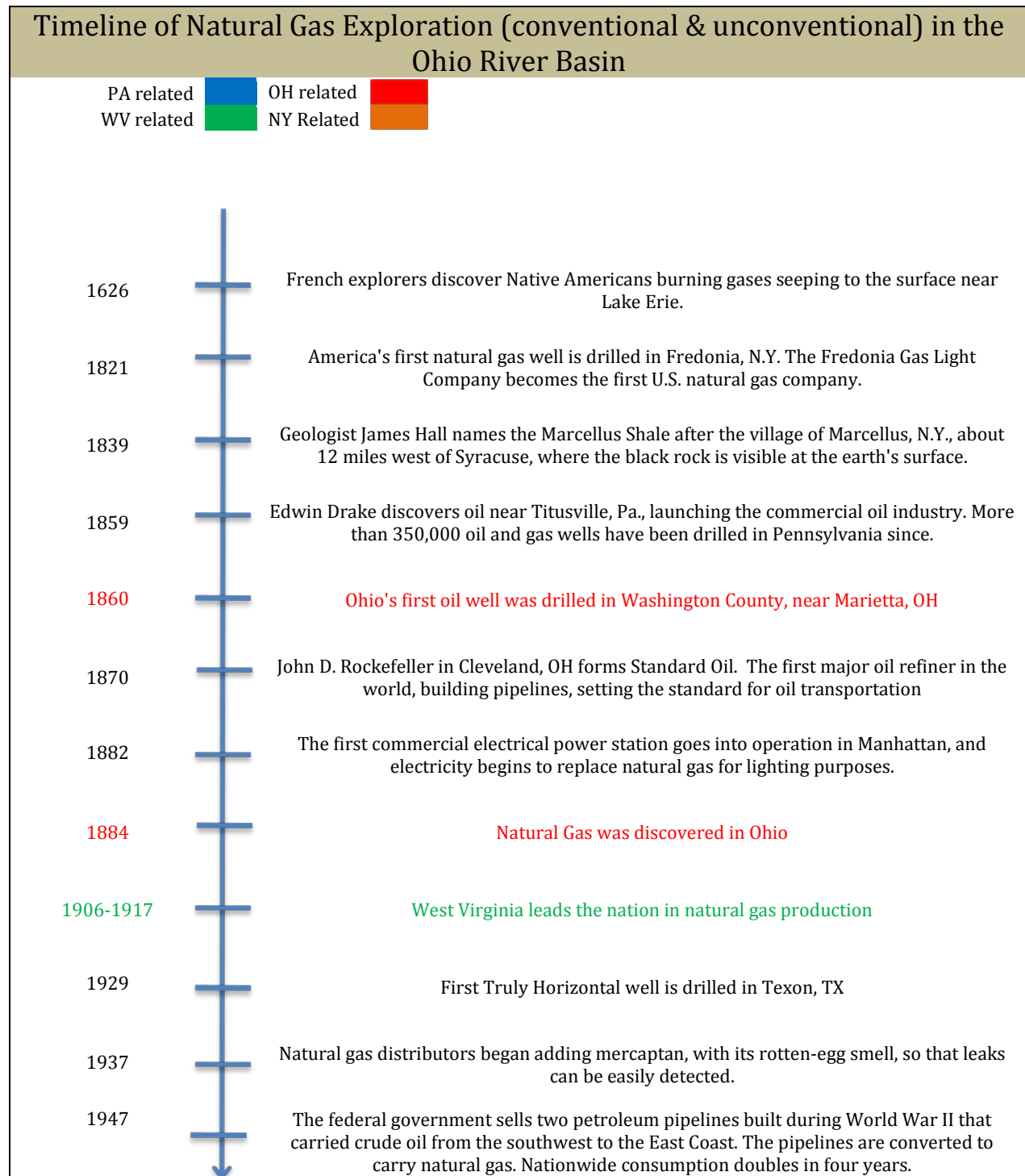


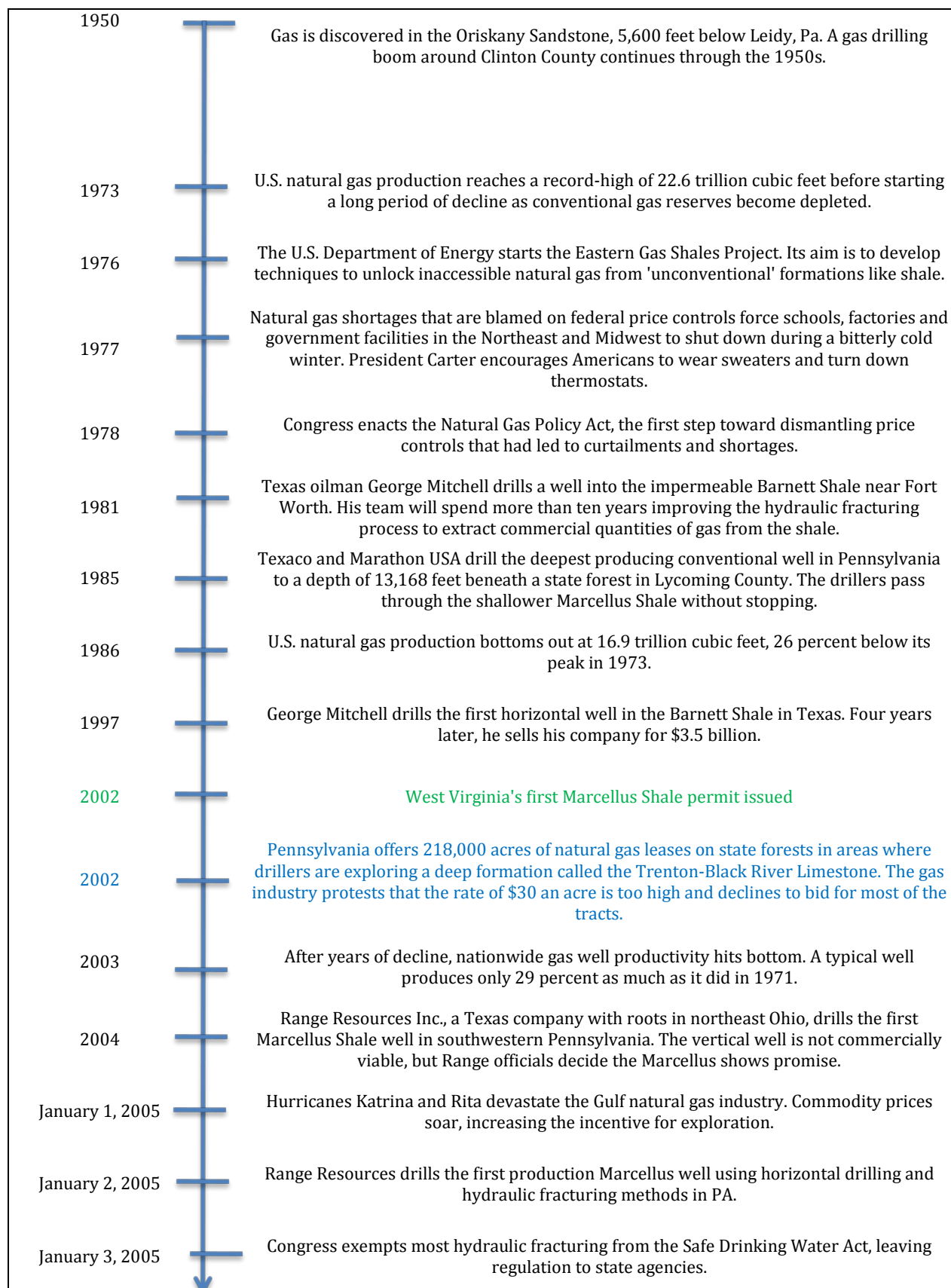
Figure 2 Shale Gas Plays of the Ohio River Basin

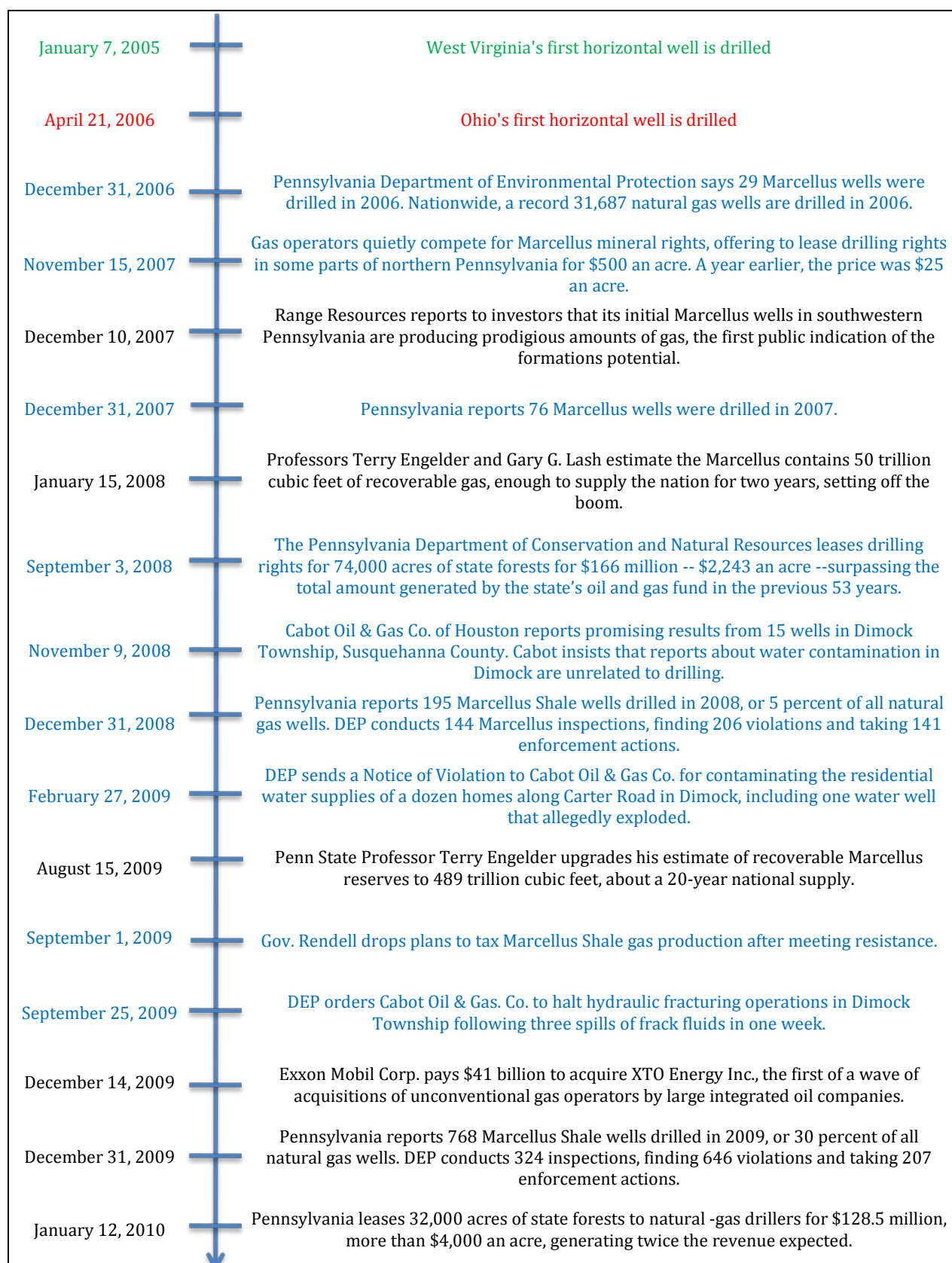
History of Shale Gas

Drilling for oil and gas in the Ohio River basin is nothing new. It has been occurring since 1859 when the first commercial oil well was drilled near Oil City, PA. In 1870 John D. Rockefeller formed Standard Oil in Cleveland, Ohio. It became the central hub for oil for the nation. Rockefeller used blue barrels via railroad to transport all of his oil to the nation. In fact the unit for oil is “bbl,” which stands for blue barrel. When the railroads raised their prices for shipping barrels of oil, Rockefeller began building pipeline to transport his oil. As a result, pipelines, refineries, and natural gas facilities sprouted in the area to distribute the kerosene and oil throughout, paving the way for today’s oil industry and infrastructure. With increased demand, oil and gas reserves had declined in the basin and much of the attention was directed to the Barnett shale in Texas and offshore reserves. For a time it was thought that all the recoverable oil and gas in the Ohio River basin had been mostly used. In 2004, an oil and gas company called Range Resources, experienced in the fracking technique from Texan oil & gas fields, brought that method to the Marcellus shale region in Pennsylvania. Initial results showed tremendous potential for extracting natural gas from Marcellus shale. As word spread about Marcellus shale, new companies came to the area to gain a

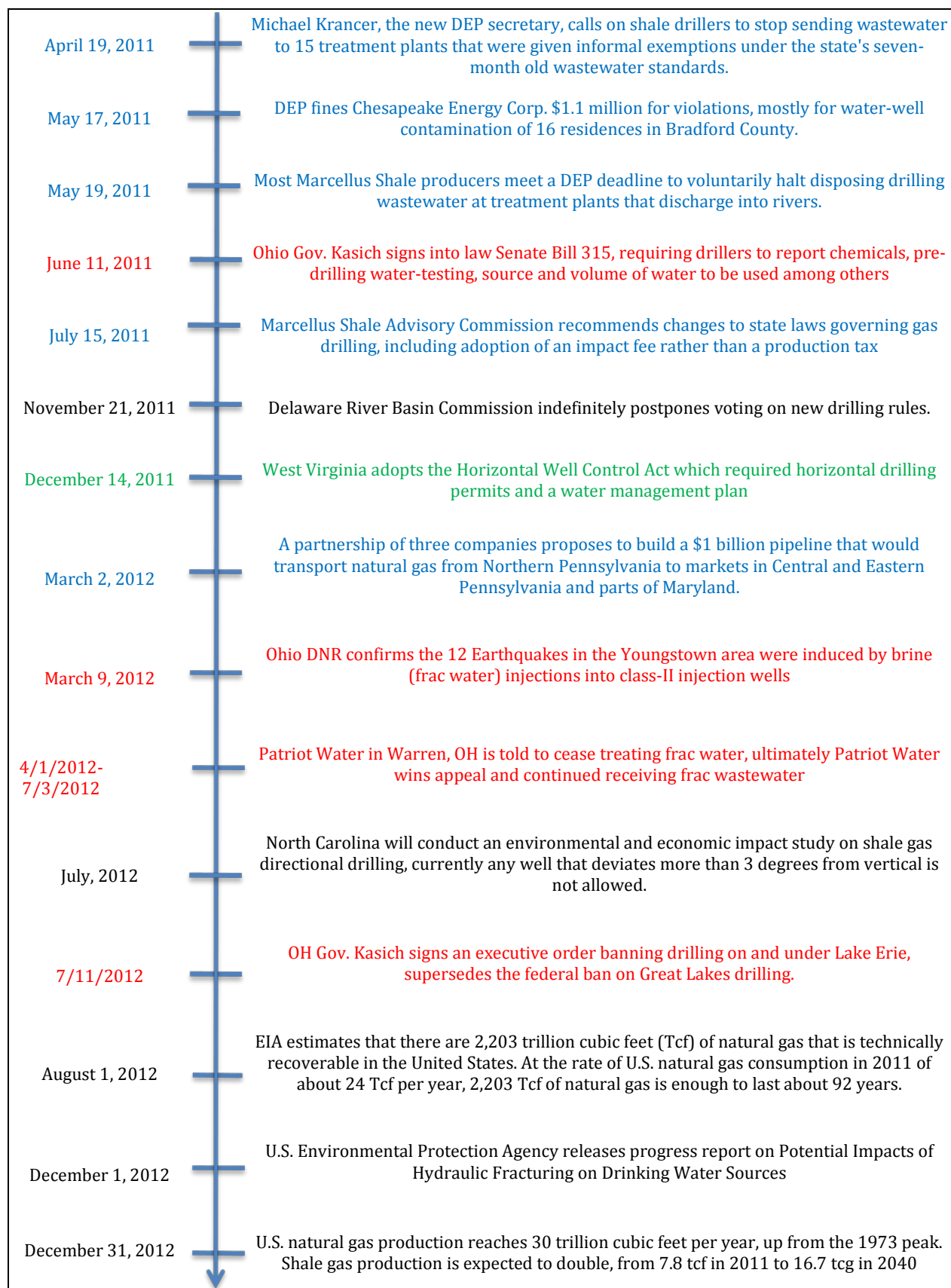
foothold in the natural gas field. Now, even more shale deposits are being discovered and proving to be rich in resources, for example Utica shale bears natural gas as well but is deeper than Marcellus shale. Since 2004, there have been over 6,000 horizontal wells drilled in the Ohio River basin. Some states of the basin have passed numerous laws to help study and reduce impacts of the drilling process. A timeline of events with regard to fracking is below.







January 28, 2010	Pennsylvania hires 68 more oil and gas inspectors, a 54 percent increase in staff, funded by increased drilling fees on Marcellus operators.
March 18, 2010	U.S. Environmental Protection Agency announces it will conduct two-year study to investigate potential adverse impact of hydraulic fracturing on water quality and public health.
April 15, 2010	DEP suspends Cabot's drilling operations, saying the Houston drilling company had not lived up to its promise to plug three natural gas wells linked to contamination in Dimock.
April 28, 2010	Range Resources tells investors that the Marcellus production rates have 'the best economics of any large scale, repeatable gas play in the U.S.'
May 18, 2010	Pennsylvania leases 33,000 acres of state forest land to Anadarko Petroleum Corp. for \$120 million to fulfill a legislative revenue-generation mandate. "Enough is enough," protests John Quigley, secretary of the Department of Conservation and Natural Resources
July 1, 2010	Ohio passed Senate Bill 5, requiring a fee per barrel to inject brine into injection wells. 5 cent in-state, 20 cent out-of-state fee
August 24, 2010	New treatment standards go into effect for gas-drilling wastewater. Environmental Protection Secretary John Hanger calls them 'the strongest legal protection in history.'
October 26, 2010	Rendell signs an executive order banning further leasing of state forests for Marcellus Shale natural gas drilling.
December 9, 2010	The Delaware River Basin Commission proposes drilling rules in its four-state watershed that are tougher than those in the rest of Pennsylvania. A drilling ban remains in effect until the rules can become final.
December 13, 2010	New York Gov. Paterson banned horizontal drilling and high volume fracking until an environmental impact statement has been completed. On June 29, 2015 the DEC concluded that high volume fracking is officially prohibited
December 16, 2010	Cabot agrees to pay Dimock residents \$4.1 million and to install whole-house gas mitigation systems in 19 houses with contaminated water supplies. DEP abandons a plan to force the company to build a \$12 million water line to serve the residents.
December 23, 2010	Ohio's First Utica-Point Pleasant horizontal well drilled
December 31, 2010	Annual U.S. natural gas production reaches nearly 22.6 trillion cubic feet, just shy of the 1973 record.
December 31, 2010	Pennsylvania reports 1,386 Marcellus Shale wells drilled in 2010, or 50 percent of all natural gas wells. DEP conducts 642 inspections, finding 1,246 violations and taking 316 enforcement actions.
February 5, 2011	New Pennsylvania well construction standards go into effect, making it less likely to allow natural gas to escape and contaminate water supplies.
February 19, 2011	Gov. Corbett rescinds Rendell's executive order banning new leases of state forests.
March 7, 2011	DEP says tests detect no unusual radioactive levels in rivers following a New York Times report alleging that radioactive drilling discharges might be contaminating Pennsylvania rivers.



January 14, 2013



U.S Coast Guard reports that Brine (Frac Water) has no classification (hazardous or nonhazardous) and cannot be transferred via barge until a classification is assigned. Green Hunter Water bought several injection wells and a storage facility in New Matamoras, OH and plans on using barges to transport frac water in the near future.

The Hydraulic Fracturing Process

Hydraulic fracturing (Figure 4) is a well stimulation process used to maximize the extraction of underground resources; including oil, natural gas, geothermal energy, and even water. The oil and gas industry uses hydraulic fracturing to enhance subsurface fracture systems to allow oil or natural gas to move more freely from the rock pores to production wells that bring the oil or gas to the surface. Even with this new drilling practice, only 10-30% of the gas is recovered from the shale.

The process of hydraulic fracturing begins with building the necessary site infrastructure including well construction. Production wells may be drilled in the vertical direction only or paired with horizontal or directional sections. Vertical well sections may be drilled hundreds to thousands of feet below the land surface and lateral sections may extend 1,000 to 6,000 feet or more away from the well. Marcellus shale ranges from 2,000 – 8,000 feet deep (Figure 3) and Utica shale is about 2,000 feet below that. The thickness of the shale plays thins out as it heads west. Marcellus ranges from 40 feet to 800 feet thick. Utica shale ranges from 70 to 1,000 feet thick.

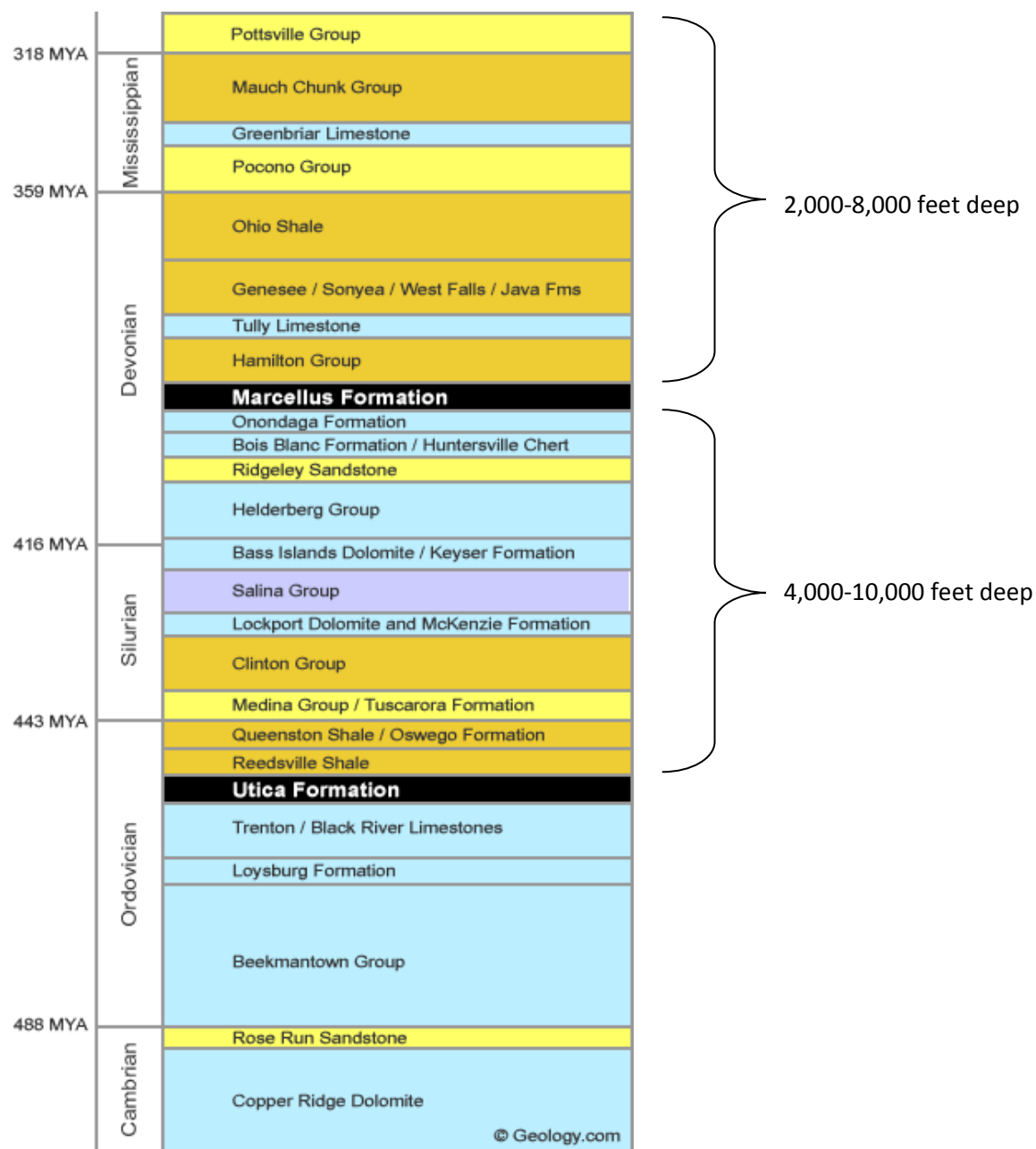


Figure 3: Timeline and deepness of geologic formations (Geology.com, 2012)

Fluids, commonly made up of water and chemical additives, are pumped into a geologic formation at high pressure during hydraulic fracturing. Water usage estimates range greatly, EPA estimates they can use up to 13 million gallons of water (U.S. EPA Office of Research and Development, 2012), USGS estimates, on average, 4.5 million gallons are used (USGS, 2013). A new report by EPA suggests 4.3-4.4 million gallons of water are injected for a typical Marcellus shale well (USEPA, 2015). When the pressure exceeds the rock strength, the fluids open or enlarge fractures that can extend several hundred feet away from the well. After the fractures are created, a propping agent (sand or ceramic beads) is pumped into the fractures to keep them from closing

when the pumping pressure is released. After fracturing is completed, the internal pressure of the geologic formation cause the injected fracturing fluids to rise to the surface where it may be stored in tanks or pits prior to disposal or recycling. Recovered fracturing fluids are referred to as flowback. Flowback estimates range greatly and are dependent on the target depth, formation, and pressure but about 10-70% of the fracturing fluids return to the surface. Disposal options for flowback include discharge into surface water, underground injection, reuse for another well or industrial treatment (centralized waste treatment, CWT).

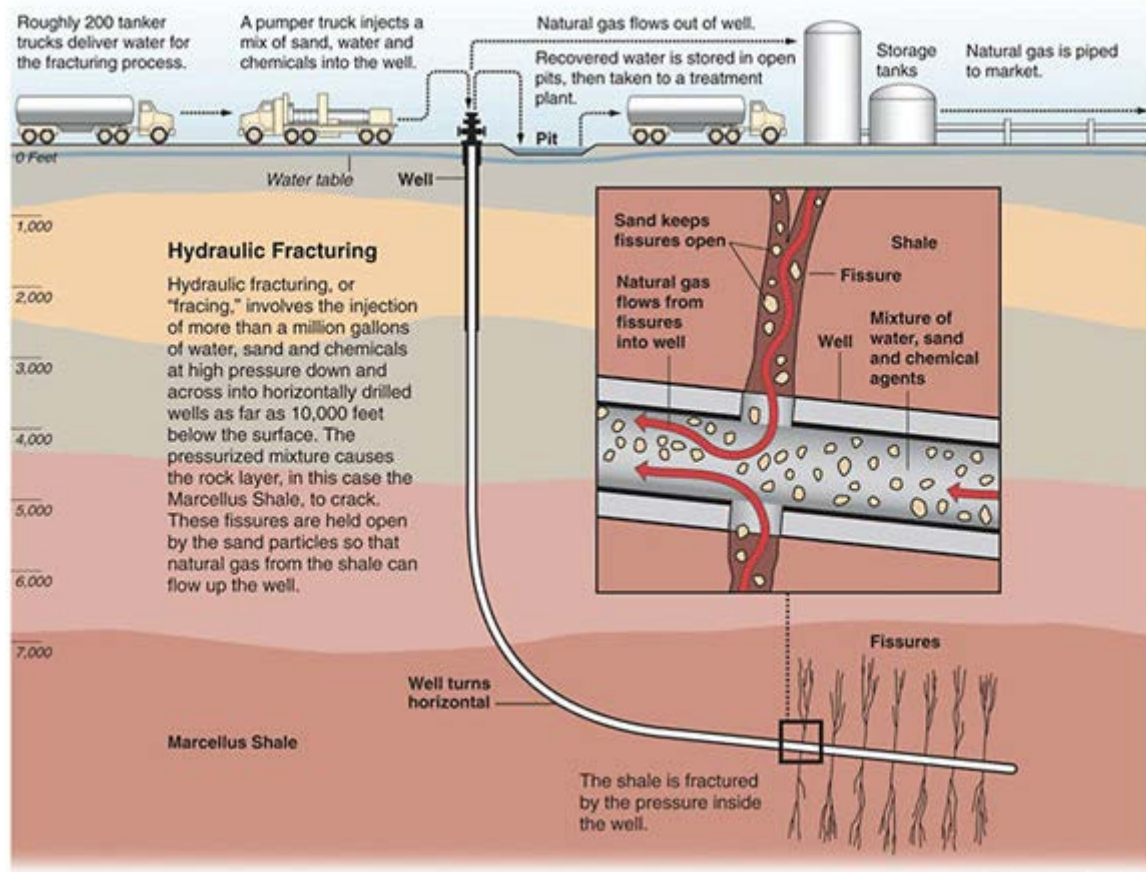


Figure 4: Hydraulic Fracturing Process (EIA, 2012)

Surface water discharges of the flowback are regulated by the National Pollutant Discharge Elimination System (NPDES) program, which requires flowback to be treated prior to discharge into surface water. Underground injection of flowback is regulated by either EPA Underground Injection Control (UIC) program or a state with primary UIC enforcement authority. Injection of natural gas production wastes must be injected into Class II injection wells only. More details on the produced wastewater are given on page 25. Drilled wells can be fracked multiple times. One fracking company estimates that they will refrac a well every five years. They also predict a well's lifespan is 20-30 years. "According to Range Resources, one of the first major horizontal drillers of Marcellus Shale, these wells typically produce (estimated ultimate recovery, EUR) gas at a rate of

about 4 MMCF (million cubic feet) per day. Over its lifetime, each horizontal well on an 80-acre surface spacing can be expected to produce a total of about 2.5 BCF (billion cubic feet) of gas at an estimated production cost of \$1.00 per MCF” (Soeder, 2009). Refracking of wells is still in its infancy and will need to be monitored closely as refracking a well every five years for 20-30 years may increase fractures in the stone and lead to increased ground or surface water contamination.

Inventory of Current Shale Gas Wells and Plays

The Ohio River basin is home to the Appalachian and Illinois Basins (Figure 2) which is made up of multiple shale plays like the Marcellus, Utica, Chattanooga, Berea, New Albany shale and others. Since 2005, when the first horizontal well was drilled into the Marcellus shale, the horizontal drilling industry has exploded. A relatively new drilling technique which requires drilling horizontally and hydraulically fracturing the shale has allowed the re-exploration of these shale plays to produce much more natural gas than previous thought.

Each state requires that each well drilled must obtain a permit first. These issued permits are effective for up to two years, which means a company can obtain a permit but choose not drill for another two years. This time gap puts a constraint on keeping track of wells in real-time. There are now over 6,000 horizontal wells in the Ohio River basin. As of October 21, 2014, within the Ohio River basin portion of the following states’, there are 3,443 drilled horizontal wells in Pennsylvania, 1,545 in Ohio, and 1,527 in West Virginia (Table 1). Pennsylvania wells in particular, have grown quickly (Figure 5). For the entire state of OH, PA, and WV, a total of 23,450 permits have been issued since 2009(as of 10-21-2014). Figure 6 shows the location of wells in the

Table 1. Issued and Drilled Horizontal Permits in OH, PA, and WV, since 2009 (updated 10-21-2014)

Table 1. Issued and Drilled Horizontal Permits in the OH, PA, and WV since 2009 (updated 10-21-2014)			
	Issued/Active Horizontal Permits	Drilled (Horizontal) Wells	Drilled Wells In the Ohio River Basin
Pennsylvania	17,974	8,537	3,443
Ohio	44 (Marcellus) 1,943 (Utica)	29 1,520	29 1,516
West Virginia	3,489	1,527	1,527
NY, IN, IL, VA, and TN all have a relatively lower number of horizontal wells. KY’s number of hydraulically fractured wells is unknown at this time			

Ohio River basin. Since the eastern part of Pennsylvania has a water resource commission, the Susquehanna River Basin Commission (SRBC), the wells in SRBC portion of the state need only

report to SRBC and do not need to report to the state, this is why Figure 6 appears to show very few wells in eastern Pennsylvania.

A large portion of Marcellus shale lies under Pennsylvania and has been drilled first since it is the shallowest of the shale plays. As demand increases, drilling companies will expand their exploration into other shale plays like the Utica and Berea. Ohio's first Utica shale well was drilled in 2010. Berea Shale is now being explored in Kentucky. Most of Kentucky's wells are nitrogen gas fractured as opposed to hydraulically fractured, but in eastern Kentucky drilling of the Berea shale requires water injection. Berea Shale well production rates are still to be determined and thus the injection amounts is also unknown at this time. In other Ohio River basin states, some horizontal drilling is taking place but those wells are far less numerous and productive compared to Marcellus.

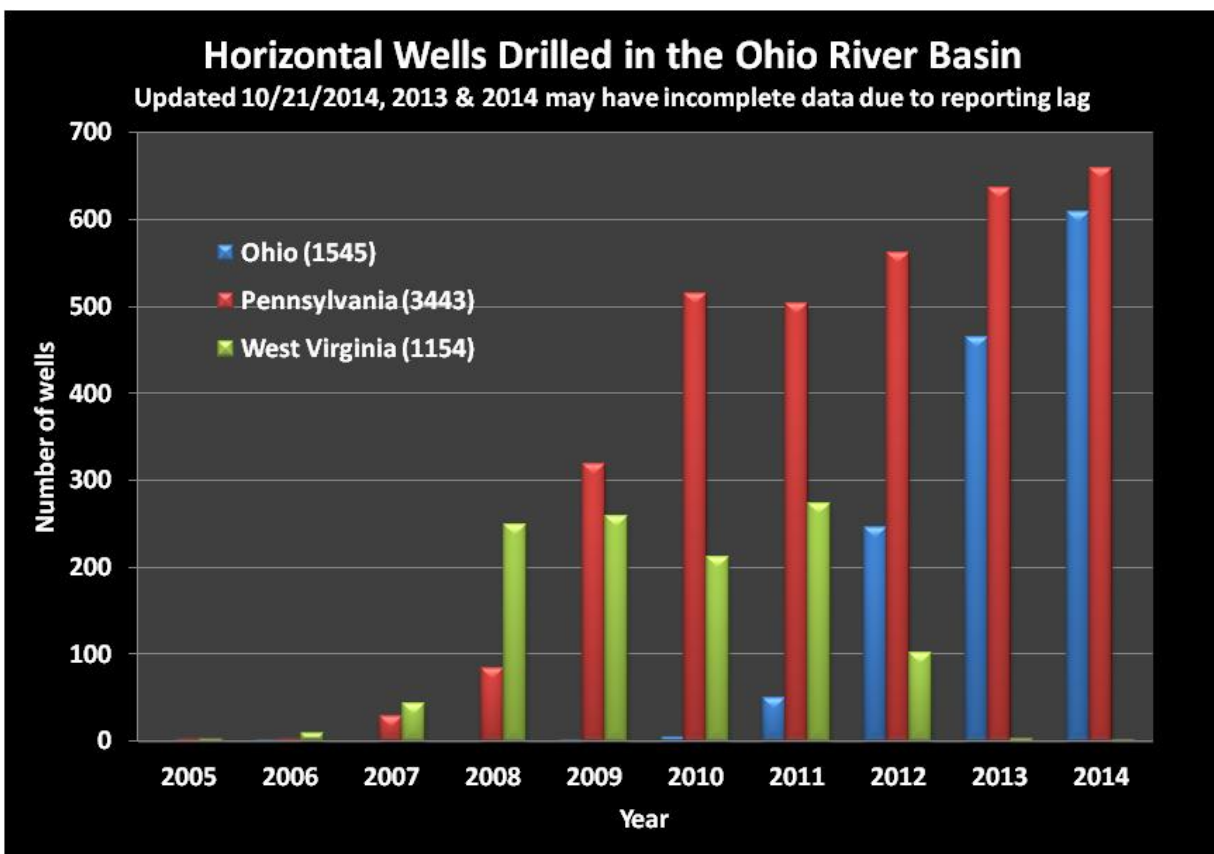


Figure 5: Drilled horizontal wells in OH, WV, and PA, for the Ohio River basin portion of each state (2013 & 2014 data may be incomplete due to reporting lag).

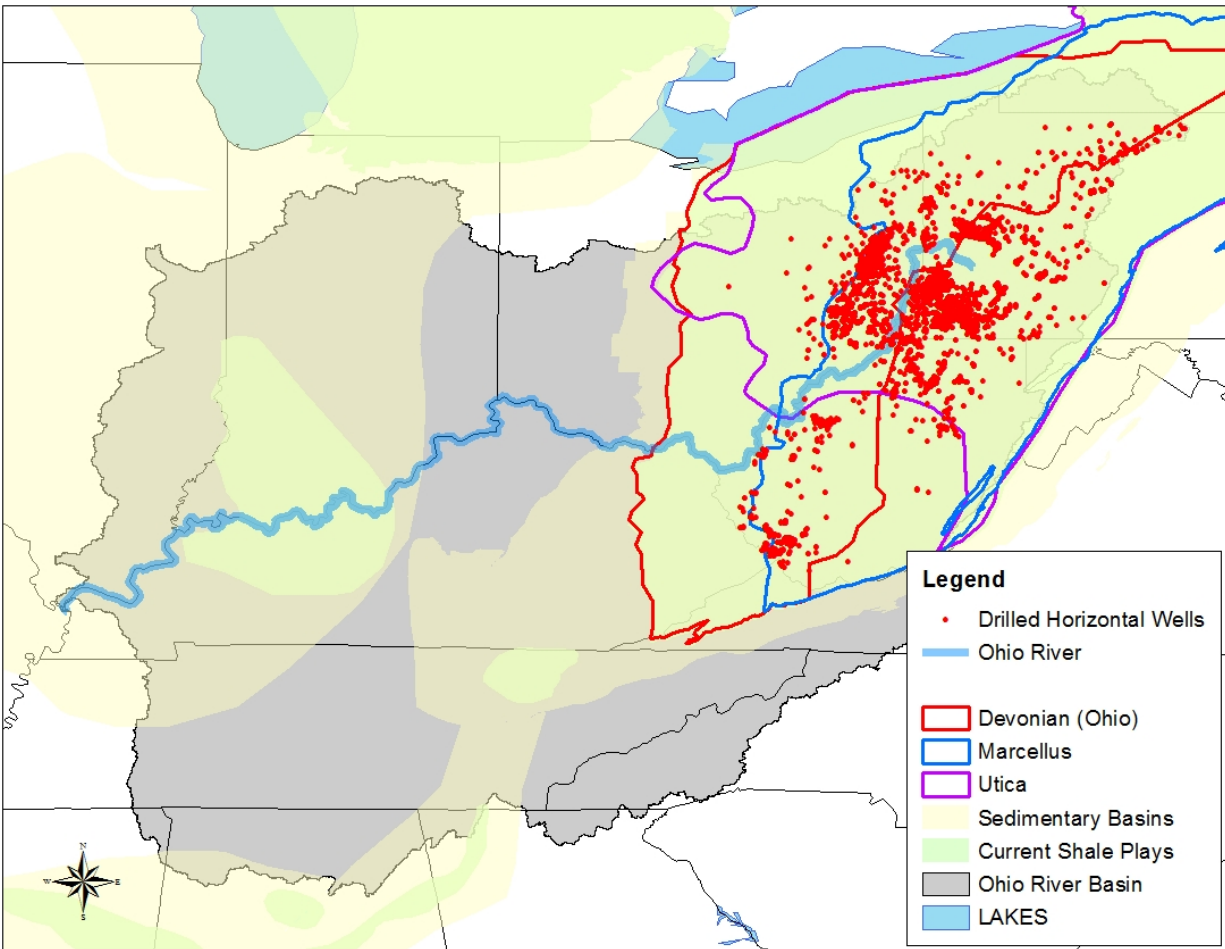


Figure 6: Map of completed horizontal wells in the Ohio River basin as of 10/21/2014

Environmental Impacts of Horizontal Drilling

Some concerns do exist with fracking a well according to EPA's "Study of the Potential Impacts of Hydraulic Fracturing." Those concerns are water availability, chemical releases, and wastewater improperly treated and/or discharged (Figure 8). Examples of each concern have already taken place and more can be expected. With regards to water availability, hydraulic fracturing fluids are usually water-based, with approximately 90% of the injected fluid composed of water. EPA estimates that water needs per well have been reported to range from 4.3 to 4.4 million gallons for shale gas production, depending on the characteristics of the formation being fractured and the design of the production well and fracturing operation. USGS estimates, on average, 4.5 million gallons of water are needed for Marcellus shale fracturing. Ohio wells have been using two to six million gallons per frac (ODNR, 2015). Five million gallons of water is equivalent to the water used by approximately 50,000 people for one day according to the same EPA's study. The source of the water may vary, but is typically ground water, surface water, or treated wastewater. An example of a surface water withdrawal site is in Figure 7 below. Industry trends suggest a recent shift to using treated and recycled produced water (or other treated wastewaters) as base fluids in

hydraulic fracturing operations (U.S. EPA Office of Research and Development, 2012). If the source of the water is from surface water, smaller streams are unable to support aquatic life if too much water is taken. Some states like West Virginia and Pennsylvania have adopted rules to assure adequate pass-by flows are met to support aquatic life. Some organizations, like The Nature Conservancy, are establishing “E-flows” which are needed to establish ecological flows to implement water allocation programs. These E-flows can help guide surface water withdrawals to prevent taking too much water.

A study of the USGS water use data may help determine water used for hydraulically fracturing but the latest USGS water use numbers were released in 2005 and do not include results from fracking. The 2010 water use data was released in 2014 but was not available in time for this report. Also, fracking does have the potential to avoid reporting water use data to the states if they pumped the water below the state’s threshold limit (

Figure 9), unless it is required to specifically report in the permit, but this is unlikely to happen because hydraulic fracking requires large amounts of water.



Figure 7: Water withdrawal site along the Ohio River

Chemical releases are another area of concern. Once onsite, water is mixed with chemicals to create the hydraulic fracturing fluid that is pumped down the well. A list of the chemicals used is in Appendix A. The fluid serves two purposes: to create pressure to propagate fractures and to carry the proppant into the fracture. Chemicals are added to the fluid to change its properties (e.g., viscosity, pH) in order to optimize the performance of the fluid. Roughly 1% of water-based hydraulic fracturing fluids are composed of proprietary chemicals, which is equivalent to 50,000 gallons for a shale gas well that uses 5 million gallons of fluid. Hydraulic fracturing operations require large quantities of supplies, equipment, water, and vehicles. Onsite storage, mixing, and pumping of hydraulic fracturing fluids may result in accidental releases, such as spills or leaks. Released fluids could then flow into nearby surface water bodies or infiltrate into the soil and near-surface ground water, potentially reaching drinking water resources. Hydraulic fracturing requires injecting the fluid at a high pressure to fracture the rock formations. One possible consequence of this fracturing is contaminating water resources with this injected fluid. EPA is currently studying these scenarios.

Finally, wastewater from hydraulic fracturing is of concern. When the injection pressure is reduced, the direction of fluid flow reverses, leading to the recovery of flowback and produced water. “Flowback” is the fluid returned to the surface after hydraulic fracturing has occurred, but before the well is placed into production, while “produced water” is the fluid returned to the surface after the well has been placed into production. They are collectively referred to as “hydraulic fracturing wastewater” and may contain chemicals injected as part of the hydraulic fracturing fluid, substances naturally occurring in the oil-or gas-producing formation, hydrocarbons, and potential reaction and degradation products. These wastewater products are usually stored onsite in retention ponds until treatment. Potential leaks from this pond may cause harmful environmental impacts. Second, treatment of the wastewater must be dealt with. Estimates of the fraction of hydraulic fracturing wastewater recovered vary by geologic formation and range from 10% to 70% of the injected hydraulic fracturing fluid (U.S. EPA Office of Research and Development, 2012). For a hydraulic fracturing job that uses 5 million gallons of hydraulic fracturing fluid, this means that between 500,000 and 3.5 million gallons of fluid will be returned to the surface. The wastewater is generally managed through disposal into deep underground injection control (UIC) wells, treatment followed by discharge to surface water bodies, or treatment followed by reuse

The environmental impacts of horizontal drilling can vary greatly. According to the Associated Press, “there were 499 complaints in PA alleging that oil and gas drilling polluted or otherwise affected water wells. 398 complaints were filed in 2013. Pennsylvania has confirmed at least 106 water-well contamination cases since 2005. Ohio had 37 complaints in 2010 and no confirmed contamination of water supplies; 54 complaints in 2011 and two confirmed cases of contamination; 59 complaints in 2012 and two confirmed contaminations; and 40 complaints for the first 11 months of 2013, with two confirmed contaminations and 14 still under investigation, although an ODNR spokesman said none of the confirmed cases were related to fracking. West Virginia has had about 122 complaints that drilling contaminated water wells over the past four years, and in four cases the evidence was strong enough that the driller agreed to take corrective action, officials said” (Begos, 2014). This news report can be somewhat misleading. For example, in Pennsylvania, the number of private water supply systems impacted by oil and gas operations includes conventional wells in addition to unconventional wells. The public can go to [http://files.dep.state.pa.us/OilGas/BOGM/BOGMPortalFiles/OilGasReports/Determination Letters /Regional Determination Letters.pdf](http://files.dep.state.pa.us/OilGas/BOGM/BOGMPortalFiles/OilGasReports/Determination%20Letters/Regional%20Determination%20Letters.pdf) to view this information. In March 2012, Ohio DNR confirmed that 12 earthquakes in the Youngstown, OH area were induced by frac water injections into a class-II injection wells.

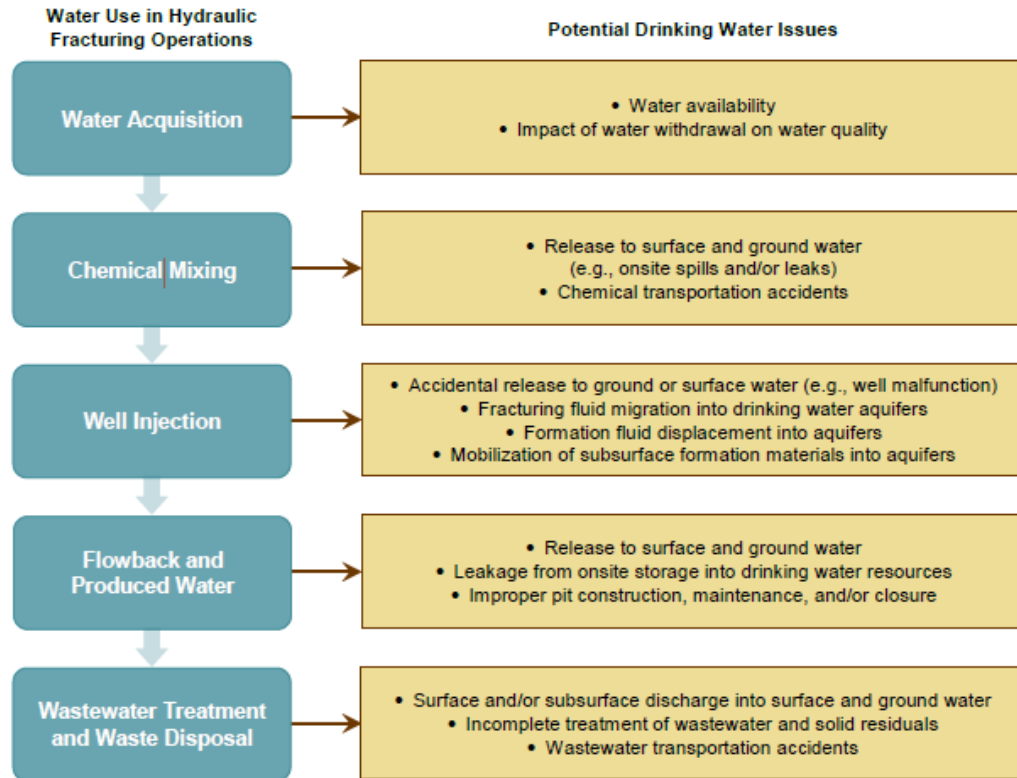


Figure 8: Potential drinking water issues associated with each stage of the hydraulic fracturing water cycle (U.S. EPA Office of Research and Development, 2012)

Current Water Use for Fracking

Water use for hydraulic fracturing varies depending on many factors, including vertical well depth, horizontal well length, geology, and composition of the fracturing fluid. Water use per well, even in the same basin and play, can vary widely. Water use reporting is also very dependent on the regulations and record keeping of each state. Each state within the Ohio River basin monitors the water used by companies/facilities differently. There are many different water use reporting threshold requirements within the basin (

Figure 9) and within a state (see ORSANCO's "Inventory of Water Resource Laws and Regulations in the Ohio River Basin" report).

The source of the water for hydraulic fracturing is surface water, ground water, or reused hydraulic fracturing wastewater. In the Ohio River basin, surface water is the primary source (USEPA, 2015). Reuse of hydraulic fracturing wastewater can reduce the amount of surface water needed. The median reuse of wastewater as a percentage of injected volume in Pennsylvania is 18% (USEPA, 2015). The water is usually self-supplied by the industry, purchased from a public water system or purchased from local land owners. Self-supplied water usually occurs through a permitted direct withdrawal from a surface or ground waters. While these direct withdrawals are based on capacity to pump, they do not report the amount withdrawn until one year later. This

creates a lag time in order to track water used. In Pennsylvania and West Virginia, water withdrawals must comply with pass-by flows so as to not harm the water source quality and quantity.

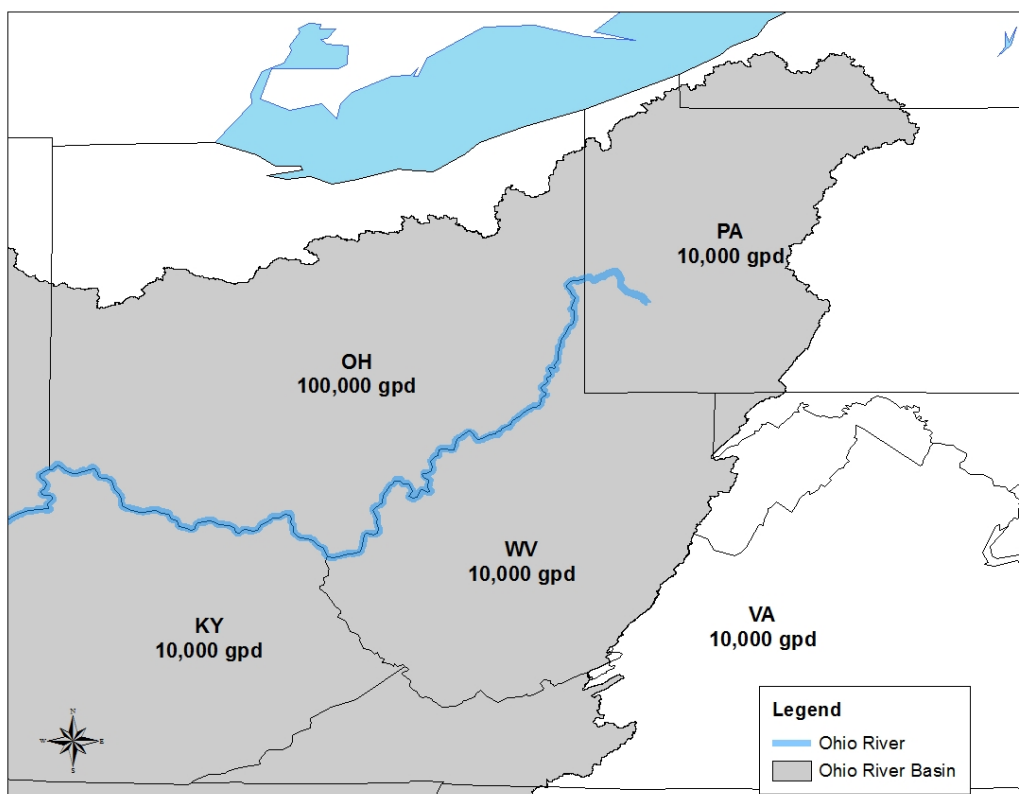


Figure 9: States' Water Withdrawal Reporting/Registration Threshold (in gallons per day, gpd)

Challenges occur when trying to track down water use for a particular well from a cradle to grave scenario. Water withdrawn from a source may go to several different pads, and those well pads may have multiple wells, or a permit may never get to the drilling stage. Also, the water may be pumped to a holding pond but never used. These and many other scenarios may happen. Water withdrawal data has been obtained for several Ohio River basin states (Figure 10) but there are limitations to it. For example, data did not become reliable until 2011. Figure 10 may serve well as an easy way to view water withdrawal points instead of volumes. It shows that there are very few water withdrawal locations coming from the Ohio River. In terms of water use, it is easier to present the information in terms of water use per well. We know from literature and FracFocus website (a website with mandatory reporting by the oil and gas industry for some states) that 4.3 to 4.4 million gallons of water are used per well (USEPA, 2015) in Pennsylvania. We know there over 6,000 wells in the Ohio River basin. Meaning, since 2009, about 25.8 to 26.4 billion gallons of water have been used to hydraulically fracture wells or 4.3 to 4.4 billion gallons per year. For comparison, in the Ohio River basin, the water consumed per year is 700 billion gallons or 0.6% of the consumed water is used for hydraulic fracturing. The water withdrawal data (**Error! Reference source not found.**) which the states provided accounts for less than 50% of the amount used per well from literature reviews, suggesting using water use per well is a more reliable method.

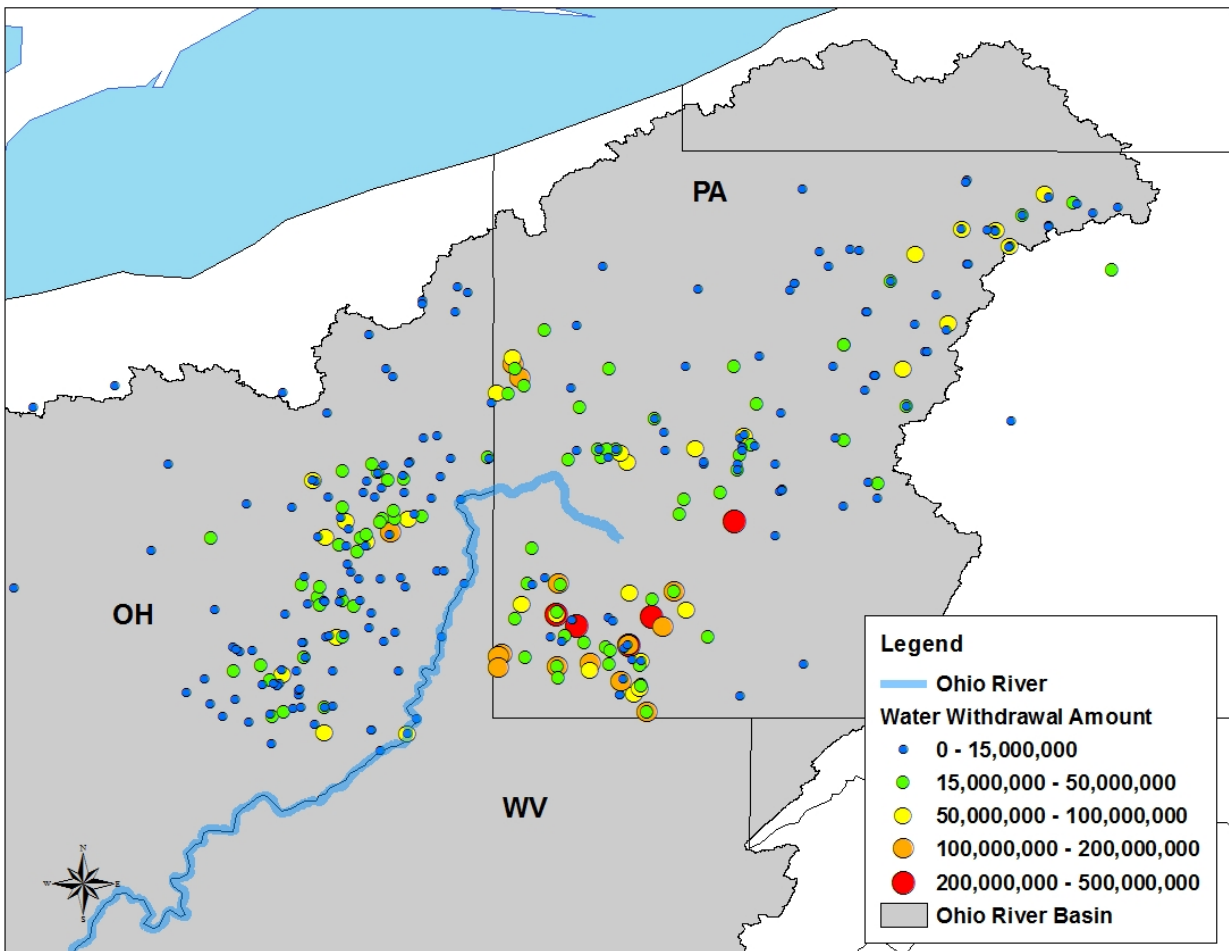


Figure 10. Hydraulic fracking water withdrawal sites and amount. This map serves well as a way to view withdrawal locations and not volumes due to uncertainty in volumes reported.

The trend for more water consumption only continues to grow for PA, WV and OH (Figure 11). As more wells are drilled, more freshwater is needed. Monitoring and assessing the amount of water withdrawn, injected, and returned is an important process in order to protect water quality and quantity.

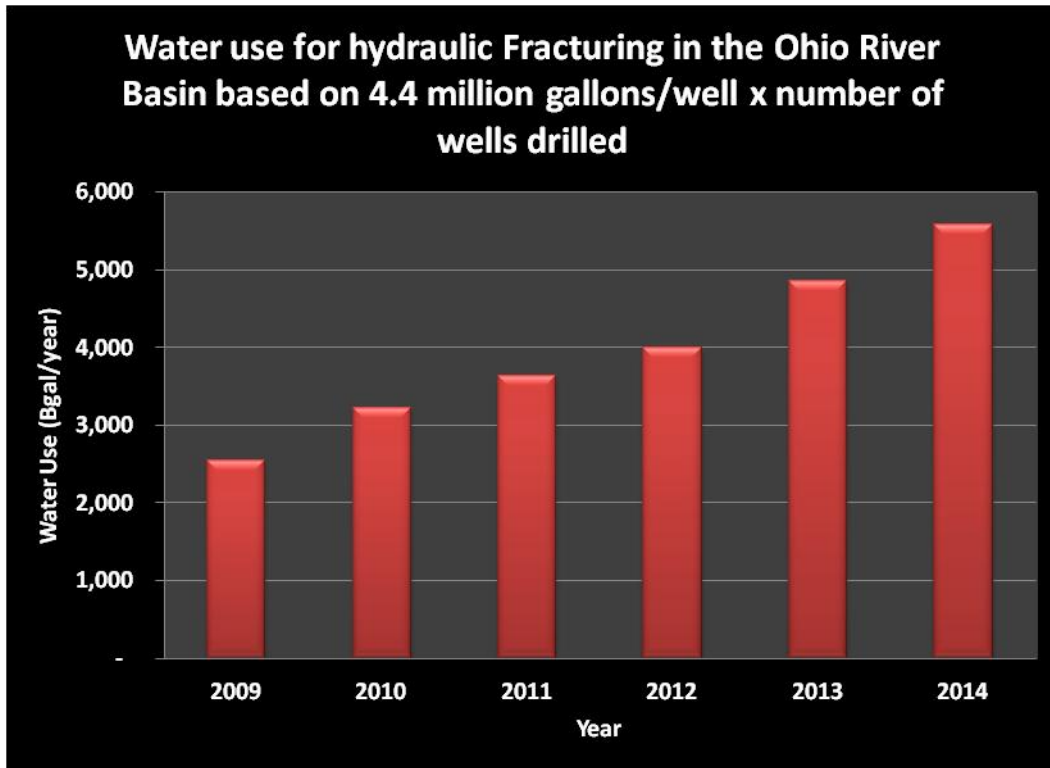


Figure 11: Water Consumed, in gallons/year, by Hydraulic Fracturing based on 4.4 million gallons/well x number of wells drilled

Hydraulic Fracturing Wastewater

An average horizontal well uses about 4-5 million gallons of water to frac it. About 10-70% of that flows back over the life of the well, called flowback and produced wastewater, although multiple definitions do exist. One fracking company estimates that 10-30% of the injected water flows back over the life of the well. The characteristics and volume of the flowback and produced water vary by well, formation, and time. For larger companies, reusing the flowback is more cost effective than treating and disposing of it. The larger companies can also buy flowback from other companies to help reduce costs of buying clean freshwater or pumping river water from a farther source. For smaller companies that have few wells to frac, they may have to either sell the flowback water for reuse to another company or legally dispose of it.

The wastewater characteristics are important for understanding the potential impacts on drinking water resources. Wastewaters are generally high in total dissolved solids (TDS), especially waters from shale formations, with values ranging from less than 1,000 mg/L to hundreds of thousands of mg/L (USEPA, 2015). The TDS from shale formations are typically dominated by sodium and chloride and may also include elevated concentrations of bromide, bicarbonate, sulfate, calcium, magnesium, barium, strontium, radium, organics, and heavy metals (USEPA, 2015) (Table 2).

Table 2. Compiled minimum and maximum concentrations for various geochemical constituents in unconventional shale gas produced water (USEPA, 2015) and whether or not the parameter is monitored for by ORSANCO in the Ohio River. Other constituents not listed may exist.

Parameter	Unit	Shale Gas ^a	Monitored by ORSANCO?
Alkalinity	mg/L	160-188	✓
Bicarbonate	mg/L	ND-4,000	✓
Conductivity	us/cm	479-763,000	✓
Nitrate	mg/L	ND-2,670	✓
Oil and Grease	mg/L	4.7-7.9	<input type="checkbox"/>
pH	SU	1.21-8.36	✓
Phosphate	mg/L	ND-5.3	✓
Sulfate	mg/L	ND-3,663	✓
Radium-226	pCi/g	0.65-1.031	<input type="checkbox"/>
Aluminum	mg/L	ND-5290	✓
Boron	mg/L	0.12-24	<input type="checkbox"/>
Barium	mg/L	ND-4,370	✓
Bromide	mg/L	ND-10,600	✓
Calcium	mg/L	0.65-83,950	✓
Chlorine	mg/L	48.9-212,700	✓
Copper	mg/L	ND-15	✓
Fluorine	mg/L	ND-33	<input type="checkbox"/>
Iron	mg/L	ND-2,838	✓
Lithium	mg/L	ND-611	<input type="checkbox"/>
Magnesium	mg/L	1.08-25,340	✓
Manganese	mg/L	ND-96.5	✓
Potassium	mg/L	0.21-5,490	<input type="checkbox"/>
Sodium	mg/L	10.04-204,302	✓
Strontium	mg/L	0.03-1,310	<input type="checkbox"/>
Zinc	mg/L	ND-20	✓

(-), no value available; ND, non-detect

^a n = 541

Currently, it has proven difficult to track the cycle of water used for fracking, this includes: identify the source of a water withdrawal for a certain well, determine the amount withdrawn, the amount injected, the amount that flowed back, and where the flowback was taken. It is possible to track sections of the water cycle depending on the record keeping and regulations of the state. Pennsylvania, for example, electronically records what happened to the wastewater via a website called “waste reports.” There are multiple methods to dispose of the wastewater.

- 1) Reuse/recycle
- 2) Public Sewage Treatment Plant

- 3) Industrial treatment (CWT)
- 4) Class II injection wells Disposal
- 5) Road Spreading

Reuse/Recycle

Current trends indicate that most companies are reusing the wastewater as much as possible (Figure 12) especially in Pennsylvania where injection wells are limited. Some companies claim nearly 100% is being reused. A review of Pennsylvania's waste reports indicate that, since 2010, 70% (3.6 billion gallons) of the waste water from unconventional wells is being reused for another unconventional well (Figure 13).

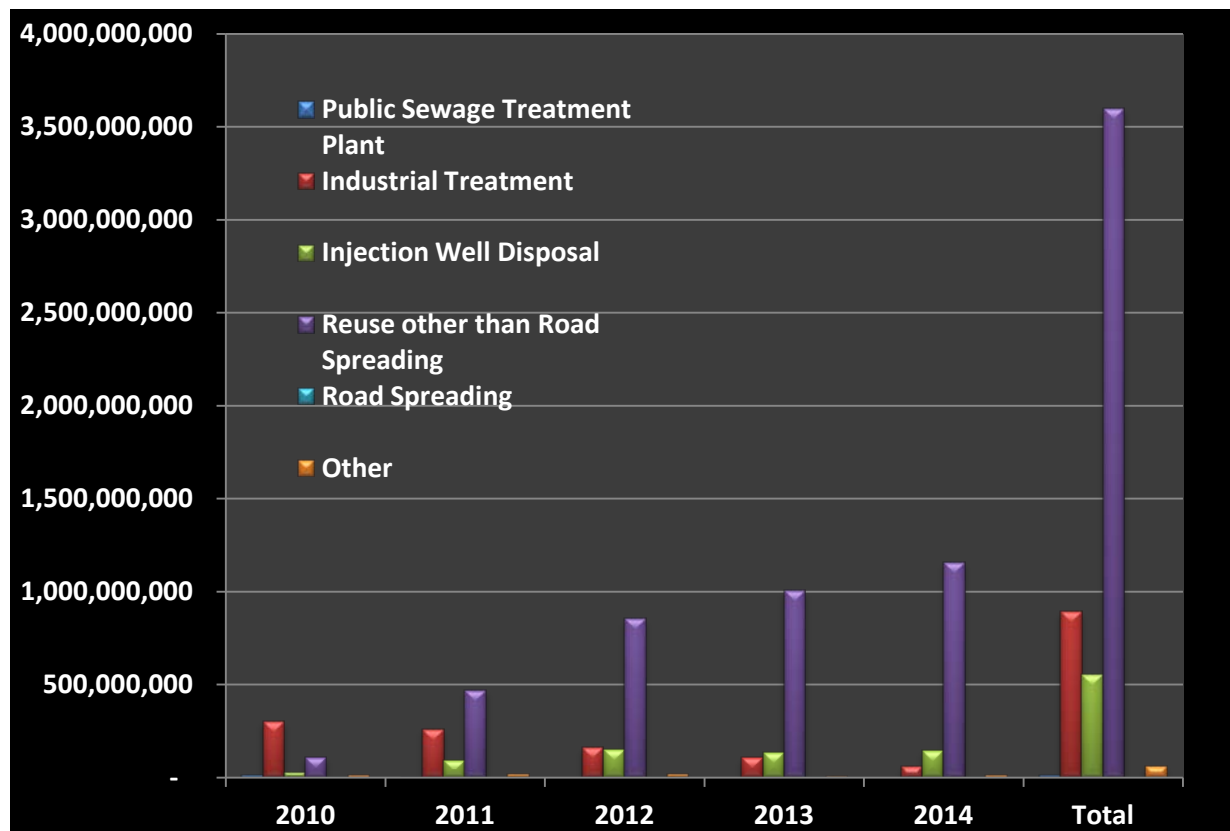


Figure 12: Disposal Method Trends for Pennsylvania's Unconventional Wells, since 2010

Public Sewage Treatment Plant

Another option to dispose of hydraulic fracturing wastewater is to send it to a public sewage treatment plant. In Pennsylvania, this practice has since stopped and the last report of it was in 2011. In Ohio and West Virginia it has also stopped, but it is legal in Ohio to dispose of brine wastewater via a public sewage treatment plant from oil and gas drillers as long as it meets certain criteria.

Industrial Treatment (Centralized Water Treatment)

Another disposal method option is industrial treatment or centralized water treatment (CWT). A CWT is defined as a facility that accepts waste from the oil and gas sector. The fate of the

treated effluent also varies from reuse for another well (zero discharge), direct discharge to a receiving water body, indirect discharge to a POTW or a combination of these. There are 11 CWTs in Ohio, 39 in Pennsylvania, and 6 in WV (USEPA, 2015). Most of the 39 CWTs in Pennsylvania are zero discharge facilities, meaning they do not discharge to surface waters or POTWs, and they often do not include TDS removal (USEPA, 2015).

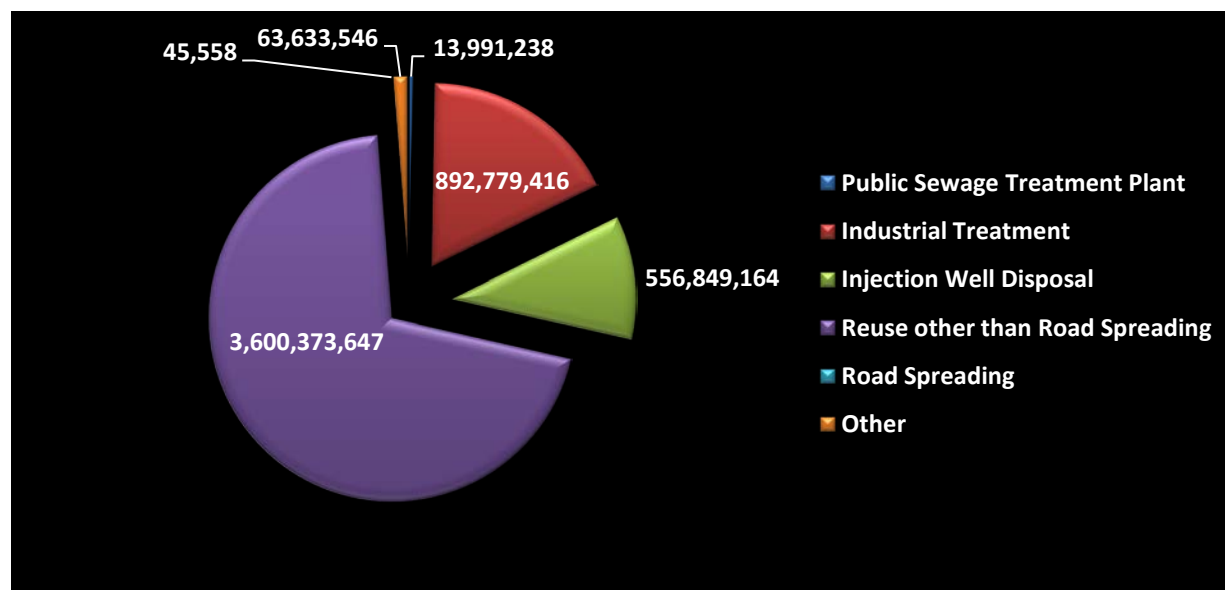


Figure 13: Disposal Methods of Produced and Flowback Wastewater from Pennsylvania's Unconventional Wells, since 2010

Class II Injection Wells

Oil and gas operators could send the frac wastewater to an underground injection well. There are approximately 8 class II injection wells in Pennsylvania, 200 in Ohio and 53 in West Virginia (Figure 1). These wells can accept wastewater from any state or out of basin and is not uncommon for this to happen, additional out of state taxes may apply though. In Pennsylvania, the trend is rising for Injection well disposal but this may be a function of an increase in drilling. The problem with underground injection is it may cause small earthquakes near the well. In 2012, Ohio Department of Natural Resources determined, in a preliminary report (Ohio Department of Natural Resources, 2012), that the 12 low magnitude earthquakes felt in the area were caused by fracking wastewater injected into the injection wells along a previously unknown fault line. The well responsible for these earthquakes has since been closed. Ohio now requires seismographs be placed near injections wells when necessary.

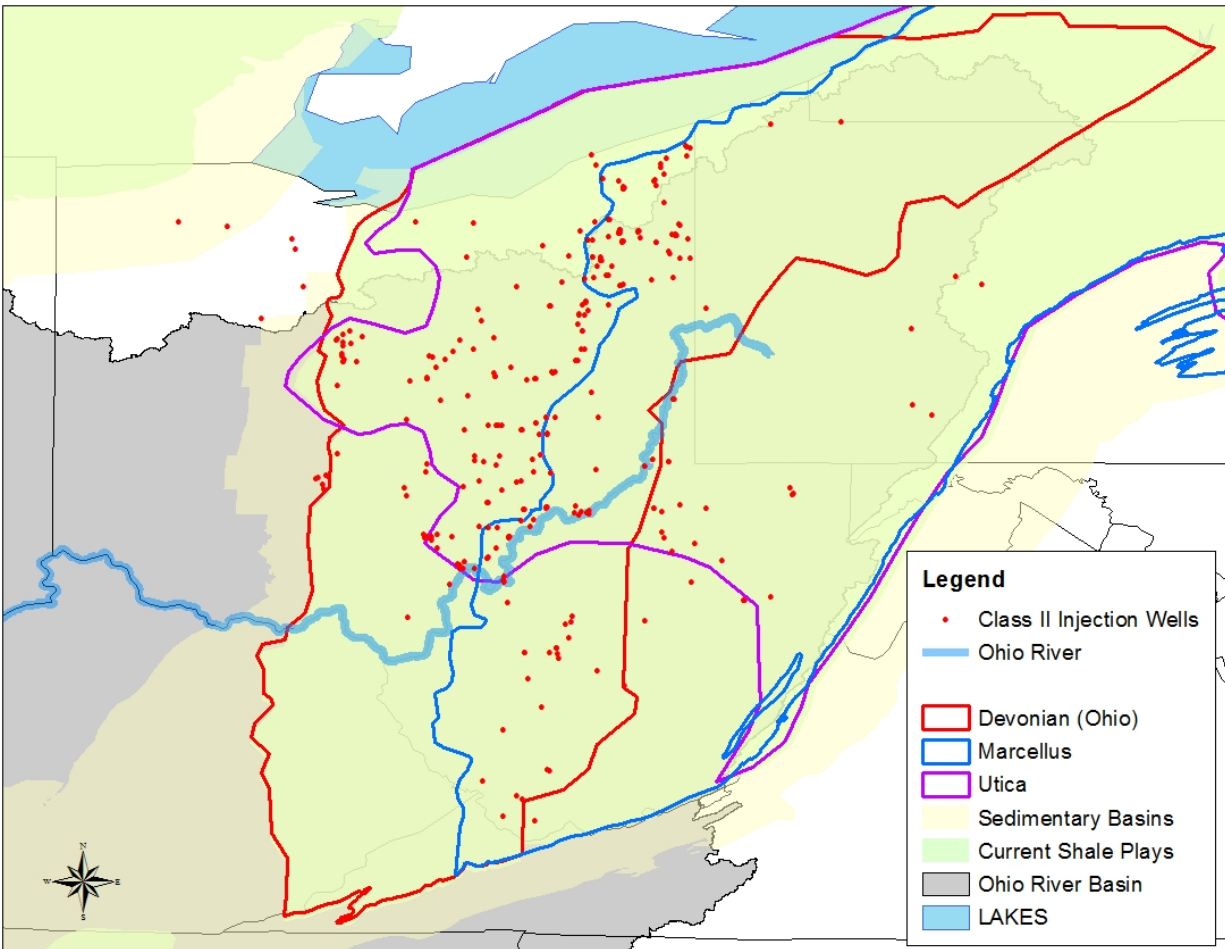


Figure 14: Class II Brine Injection Wells of PA (8), OH (200), and WV (53)

Road Spreading

Road spreading of fracking wastewater (i.e. brine) is a common misconception. Road spreading of wastewater from horizontal wells is not allowed in OH, PA, or WV. While there are some small numbers reported in Pennsylvania's waste reports, this is possibly due to submission errors.

Any combination of the disposal methods is also an option. Reusing of the flowback is on the rise and accounts for 70% of all wastewater from horizontal wells in Pennsylvania. While reuse of frac wastewater is a great option, it is not perfect. Eventually the reused flowback will become nonviable for reuse again and must be disposed of in another manner. Injection wells can only take so much wastewater before they too become a nonviable option. Injection well operators are concerned with the total suspended solids in the wastewater. As the total suspended solids in the wastewater increases, it is more likely to clog the micro fractures in the injection wells and render the disposal well useless. We will need to continue to monitor the disposal, use, and volumes of the wastewater as other disposal methods disappear and new methods are needed by the oil and gas industry.

Shale Gas Reserves, Production, and Future Growth

The Ohio River basin is home to two natural gas basins, the Appalachian and Illinois Basins (Figure 2). There exists multiple shale gas plays in each basin. Estimates range greatly for natural gas from year to year and from agency to agency. Agencies also define their estimates of shale gas in different ways. It is very difficult to estimate gas until production data is released by the company and then by the state. Pennsylvania withheld the Marcellus shale production data for the first five years of drilling. In 2011, USGS estimates there exist 84 trillion cubic feet (TCF) of natural gas in the Marcellus Shale alone (USGS, 2011). The Energy Information Administration (EIA) estimates 140 TCF of natural gas exist in the same shale formation in 2012. **Error! Reference source not found.** shows the two agencies that estimate natural gas reserves for all shale gas plays in and around the Ohio River basin. Multiple factors take place in estimating reserves like organic richness, thermal maturity, well spacing, area with potential, production results, and others.

Table 3. USGS and EIA Shale Gas Reserve Estimates

EIA Estimates of Unproved technically recoverable resource assumptions by Basin in the Ohio River Watershed*								
(trillion cubic feet)	2006	2007	2008	2009	2010	2011	2012	2013
Appalachian Basin	15	15	14	51	59	441	187	Not released Yet
Marcellus						410	140	
Utica							15.7	
Cincinnati Arch						1	1	
Big Sandy							7	
Chattanooga							1.6	
Other							21.7	
Illinois Basin	3	3	3	4	4	11	11	Not released Yet
New Albany							11	
<i>Subtotal</i>						452	198	
<i>Percent of total of all shale plays in the Lower 48</i>						55%	41%	
<i>*shale plays that extended beyond the watershed boundary were included</i>								
USGS Estimates of mean continuous gas (undiscovered technically recoverable resources) by Shale play								
	2006	2007	2008	2009	2010	2011	2012	2013
Appalachian Basin						148.18		
Marcellus						84.12		
Utica							37	
All Others						64.06*		
<i>*data is from 2002</i>								

Utica shale estimates are also highly variable. Since drilling just began in 2010 little production data exists. EIA doesn't make predictions until they have 5 years of data. **Error! Reference source not found.** shows the current USGS Utica Shale estimates (USGS, 2012).

The EIA is responsible for making predictions on America's energy use and growth. They estimate that our current annual natural gas production of 23 tcf will increase to 34 tcf by year 2040 (Figure 15), a 47% increase. The United States consumed more natural gas than it produced in 2010, importing 2.6 tcf from other countries. The EIA, in 2012 estimated that domestic natural gas production grows more quickly than consumption. As a result, the United States becomes a net exporter of natural gas by around 2022, and in 2035 net exports of natural gas from the United States total about 1.4 tcf.

Domestic natural gas production grows faster than consumption and the U.S. becomes a net exporter of natural gas around 2020

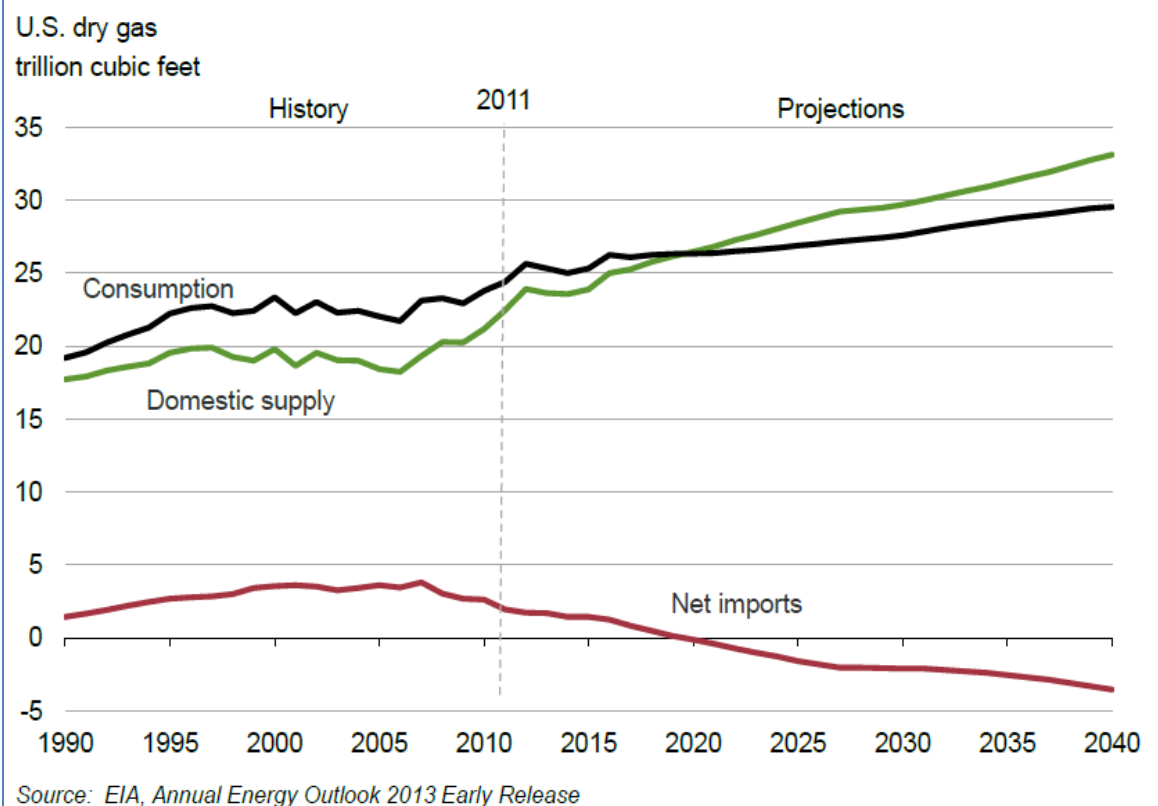


Figure 15: EIA natural gas production (U.S. Energy Information Administration, 2012)

In the electric generating sector, natural gas use in power generation will grow 26% from 2009 to 2035. The increase in production of natural gas is primarily due to continued development of shale gas resources. Shale gas is the largest contributor to production growth. By 2035, shale gas accounts for 50 percent of total U.S. natural gas production. New natural gas power plants are currently being built in Pennsylvania and Kentucky.

Because we know the extent of Marcellus shale (104,067 sq-miles), the average well spacing (4.9 wells/ sq-mile), percent of area with potential (18%), and the average recovery (EUR) from a well (1.56 bcf) we can calculate how much natural gas is technically recoverable (141 tcf). **Error! Reference source not found.** shows how each agency comes up with their natural gas reserve numbers. We can also estimate how many wells will be potentially drilled in order to extract all the natural gas. Based on today's average well spacing and area, the Marcellus shale would need over 90,000 wells drilled to extract all recoverable natural gas (**Error! Reference source not found.**).

Table 4. Marcellus unproved technically recoverable resources: AEO2011, USGS 2011, and AEO2012

Estimate	Area (square miles)	Well spacing		Percent of area untested	Percent of area with potential	Average EUR (billion cubic feet per well)	TRR (billion cubic feet)
		Acres	Wells per square mile				
AEO2011 (as of 1/1/2009)							
Marcellus	94,893	80	8	99%	34%	1.62	410,374
USGS (2011 assessment)							
Marcellus	104,067	132	4.9	99%	18%	0.93	84,198
Foldbelt	19,063	149	4.3	100%	5%	0.21	765
Interior	45,156	149	4.3	99%	37%	1.15	81,374
Western	39,844	117	5.5	99%	7%	0.13	2,059
AEO2012 (as of 1/1/2010)							
Marcellus	104,067	132	4.9	99%	18%	1.56	140,541
Foldbelt	19,063	149	4.3	100%	5%	0.21	757
Interior	45,161	149	4.3	99%	37%	1.95	137,677
Western	39,844	117	5.5	100%	7%	0.13	2,107

Table 5. Potential number of wells needed to extract the recoverable natural gas

Number of Wells Needed to extract all recoverable Natural Gas							
Shale Play	Area (square miles)	Average well spacing (wells per square mile)	Percent of area untested	Percent of area with potential	Average EUR (billion cubic feet per well)	Number of Potential wells	TRR (billion cubic feet)
Marcellus	104,067	5	99	18	1.56	90,216	140,565
Utica	16,590	4	100	21	1.13	13,936	15,712

Conclusion

There are over 6,000 completed horizontal wells drilled in the Ohio River basin. Pennsylvania is now the fastest growing natural gas producing state (Figure 16). With each well there exists a potential to leak chemicals into the environment, use up available water for other in-stream purposes, contaminate surface and ground water sources, and many more. Each one of these potential problems has already occurred and only a fraction (8%) of the potential wells have been drilled. Each well requires 4.5 – 13 million gallons of consumed water. Each well can also be potentially refracked every five years for 20-30 years, increasing the need for water and contamination. Using today's technology there exists a potential for an additional 100,000 wells to extract all the recoverable natural gas from the ground. Each year the amount of water consumed to frac wells is increasing, with much of these withdrawals coming from the Ohio River basin, and some coming from smaller bodies of water compared to the Ohio River. All of these withdrawals are considered consumed. With a lack of interbasin transfer oversight within the Ohio River basin, there exists a potential for water to be transferred to other watersheds outside of the Ohio River basin. There also is a potential for wastewater to come into the Ohio River basin and injected into one of the many injection wells. Oil and gas companies are now shifting to recycling of frac wastewater, but during wet years like 2012, they may not need to withdraw from father locations like the Ohio River. A future assessment of the 2012 data and 2013 will serve well to see where the water is being withdrawn. It has proven difficult to track water use for the fracking operations from a cradle to grave situation. Many pipelines are being built to transport water, for example in Beech Bottom, WV a pipeline has been built to transport water from the Ohio River to the interior of WV and PA (completion is expected in summer of 2014). Oil and gas companies are willing to pay millions of dollars to pump water either via pipeline or truck, and will find more ways to increase profits. As of now, there is no central agency that manages the water of the Ohio River basin with a holistic approach. Each state works independently of each other yet they all share the water. With the number of wells expected to rise and the possibility of an unreliable water use reporting system in place, negative environmental impacts, and more pipelines, a well managed program is necessary to better monitor the water resources of the Ohio River basin.

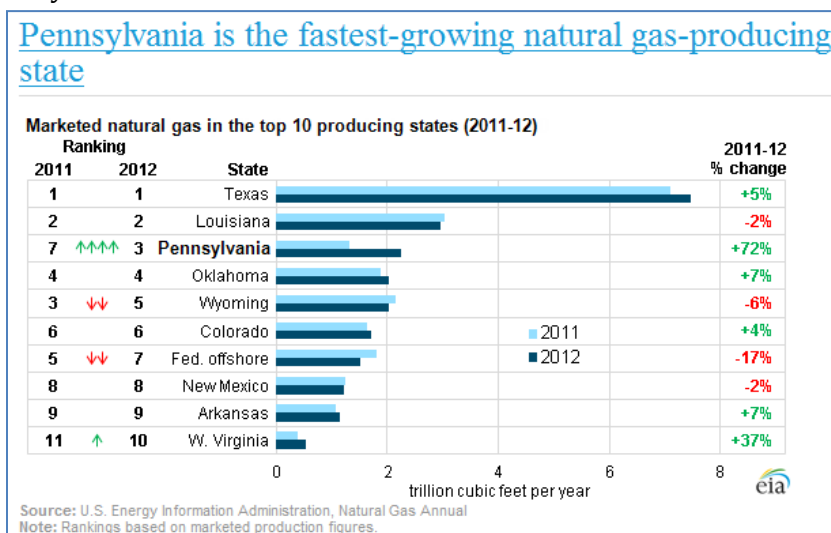


Figure 16: Gas Producing States

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Appendix A (FracFocus, 2013)

Chemicals Commonly used in Hydraulic Fracturing		
Source: http://fracfocus.org/chemical-use/what-chemicals-are-used retrieved 4/4/2013		
<u>Chemical Name</u>	<u>Chemical Purpose</u>	<u>Product Function</u>
Hydrochloric Acid	Helps dissolve minerals and initiate cracks in the rock	Acid
Glutaraldehyde	Eliminates bacteria in the water that produces corrosive by-products	Biocide
Quaternary Ammonium Chloride	Eliminates bacteria in the water that produces corrosive by-products	Biocide
Quaternary Ammonium Chloride	Eliminates bacteria in the water that produces corrosive by-products	Biocide
Tetrakis Hydroxymethyl-Phosphonium Sulfate	Eliminates bacteria in the water that produces corrosive by-products	Biocide
Ammonium Persulfate	Allows a delayed break down of the gel	Breaker
Sodium Chloride	Product Stabilizer	Breaker
Magnesium Peroxide	Allows a delayed break down the gel	Breaker
Magnesium Oxide	Allows a delayed break down the gel	Breaker
Calcium Chloride	Product Stabilizer	Breaker
Choline Chloride	Prevents clays from swelling or shifting	Clay Stabilizer
Tetramethyl ammonium chloride	Prevents clays from swelling or shifting	Clay Stabilizer
Sodium Chloride	Prevents clays from swelling or shifting	Clay Stabilizer
Isopropanol	Product stabilizer and / or winterizing agent	Corrosion Inhibitor
Methanol	Product stabilizer and / or winterizing agent	Corrosion Inhibitor
Formic Acid	Prevents the corrosion of the pipe	Corrosion Inhibitor
Acetaldehyde	Prevents the corrosion of the pipe	Corrosion Inhibitor
Petroleum Distillate	Carrier fluid for borate or zirconate crosslinker	Crosslinker
Hydrotreated Light Petroleum Distillate	Carrier fluid for borate or zirconate crosslinker	Crosslinker
Potassium Metaborate	Maintains fluid viscosity as temperature increases	Crosslinker
Triethanolamine Zirconate	Maintains fluid viscosity as temperature increases	Crosslinker
Sodium Tetraborate	Maintains fluid viscosity as temperature increases	Crosslinker
Boric Acid	Maintains fluid viscosity as temperature increases	Crosslinker
Zirconium Complex	Maintains fluid viscosity as temperature increases	Crosslinker
Borate Salts	Maintains fluid viscosity as temperature increases	Crosslinker
Ethylene Glycol	Product stabilizer and / or winterizing agent.	Crosslinker
Methanol	Product stabilizer and / or winterizing agent.	Crosslinker
Polyacrylamide	"Slicks" the water to minimize friction	Friction Reducer
Petroleum Distillate	Carrier fluid for polyacrylamide friction reducer	Friction Reducer
Hydrotreated Light Petroleum Distillate	Carrier fluid for polyacrylamide friction reducer	Friction Reducer

Methanol	Product stabilizer and / or winterizing agent.	Friction Reducer
Ethylene Glycol	Product stabilizer and / or winterizing agent.	Friction Reducer
Guar Gum	Thickens the water in order to suspend the sand	Gelling Agent
Petroleum Distillate	Carrier fluid for guar gum in liquid gels	Gelling Agent
Hydrotreated Light Petroleum Distillate	Carrier fluid for guar gum in liquid gels	Gelling Agent
Methanol	Product stabilizer and / or winterizing agent.	Gelling Agent
Polysaccharide Blend	Thickens the water in order to suspend the sand	Gelling Agent
Ethylene Glycol	Product stabilizer and / or winterizing agent.	Gelling Agent
Citric Acid	Prevents precipitation of metal oxides	Iron Control
Acetic Acid	Prevents precipitation of metal oxides	Iron Control
Thioglycolic Acid	Prevents precipitation of metal oxides	Iron Control
Sodium Erythorbate	Prevents precipitation of metal oxides	Iron Control
Lauryl Sulfate	Used to prevent the formation of emulsions in the fracture fluid	Non-Emulsifier
Isopropanol	Product stabilizer and / or winterizing agent.	Non-Emulsifier
Ethylene Glycol	Product stabilizer and / or winterizing agent.	Non-Emulsifier
Sodium Hydroxide	Adjusts the pH of fluid to maintains the effectiveness of other components, such as crosslinkers	pH Adjusting Agent
Potassium Hydroxide	Adjusts the pH of fluid to maintains the effectiveness of other components, such as crosslinkers	pH Adjusting Agent
Acetic Acid	Adjusts the pH of fluid to maintains the effectiveness of other components, such as crosslinkers	pH Adjusting Agent
Sodium Carbonate	Adjusts the pH of fluid to maintains the effectiveness of other components, such as crosslinkers	pH Adjusting Agent
Potassium Carbonate	Adjusts the pH of fluid to maintains the effectiveness of other components, such as crosslinkers	pH Adjusting Agent
Copolymer of Acrylamide and Sodium Acrylate	Prevents scale deposits in the pipe	Scale Inhibitor
Sodium Polycarboxylate	Prevents scale deposits in the pipe	Scale Inhibitor
Phosphonic Acid Salt	Prevents scale deposits in the pipe	Scale Inhibitor
Lauryl Sulfate	Used to increase the viscosity of the fracture fluid	Surfactant
Ethanol	Product stabilizer and / or winterizing agent.	Surfactant
Naphthalene	Carrier fluid for the active surfactant ingredients	Surfactant
Methanol	Product stabilizer and / or winterizing agent.	Surfactant
Isopropyl Alcohol	Product stabilizer and / or winterizing agent.	Surfactant
2-Butoxyethanol	Product stabilizer	Surfactant