TECHNICAL SUPPLEMENT

NATURAL GAS EXTRACTION: ISSUES AND POLICY OPTIONS

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NARDeP
National Agricultural &
Rural Development Policy Center
A Regional Rural Development Centers Initiative

About this technical supplement

This technical supplement to the NARDeP published white paper, "Natural Gas Extraction: Issues and Policy Options," has not been peer reviewed and is made available to provide more detail on background and technical details of natural gas fracking.

Figures and Tables

The figures and tables used in this document have been cited and all were created using public funding and originally appeared in publications within the public domain.

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Cover Photo: Deep Well Natural Gas Rig, Casper, Wyoming
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http://www.blm.gov/wo/st/en/bpd.html

RRDC REGIONAL RURAL DEVELOPMENT CENTERS

NARDeP National Agricultural & Rural Development Policy Center
A Regional Rural Development Centers Initiative

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Contents

Glossary

annulus	The circular space between an oil or natural gas well casing and the sides of the wellbore
brine (saltwater)	Water with high concentrations of dissolved minerals (frequently used to describe water with total dissolved solids of 5,000 ppm or more) often produced along with oil or natural gas
Class II injection wells	Wells used for the injection of water to produce oil and gas, but not used for hydraulic fracturing operations
compressors	used to pressurize gas to the necessary level for pipeline transport
dehydration	removing any remaining water from the gas by bubbling the gas through a material that will absorb the water - often ethylene glycol
dehydrators	uses a glycol solution to extract water vapor from the gas
drilling mud	a mixture of water, minerals, and other chemical components used for a number of purposes in the well, such as cooling the drill bit, flushing drill cuttings to the surface, and providing outward pressure on the wellbore to counteract the inward pressure of the surrounding geological formations
flaring process	the process of igniting the natural gas that returns through the wellbore before the connection of the well to the pipeline
flowback water	water injected into the wellbore that returns to the surface
freeboard	the height gap between the fluid level and the top elevation of the embankment
green completion	procedures used to capture and control gas emissions from the very beginning of gas production including the capture of gases from flowback and produced water
heater-treater	used to break up emulsified petroleum liquids
Hydraulic fracturing (fracking or fracing)	the process of injecting fluids into a geologic formation to cause the fracturing of that formation
hydrocarbons	coal, oil, and natural gas
hazardous waste orphaned wells	a waste regulated by RCRA or CERCLA based on its possession of hazardous characteristics or its potential for its harm to the environment or health wells that are not actively producing oil or gas, and for which the operator is or was unknown or

	insolvent
produced water	water that was already present in the hydrocarbon-bearing formation that is forced to the surface by the natural gas extraction process
proppant	frequently silica or quartz sand - after water, the larger component of the fracturing fluid; holds the fractures created by the process open, allowing the natural gas to flow into the wellbore
secondary recovery	the injection of water into a hydrocarbon bearing formation to increase the pressure on the formation and drive additional oil or gas toward the wellbore
setback requirements	required minimum distances between oil and gas wellbores and water wells to minimize risk of interaction between the two
solid waste	Waste regulated under RCRA, which can include hazardous and non-hazardous waste
source rock	geologic formations that created hydrocarbons
surface casing	Casing that must be installed to a depth below the deepest source of fresh water encountered by the well, and must be surrounded by cement to seal both the well and the fresh water-containing formation apart from each other
sweetening	removing corrosive gases such as carbon dioxide and hydrogen sulfide
sweetening units	used to remove hydrogen sulfide from natural gas
tertiary recovery	typically involves efforts to reduce the viscosity of oil or to make it more mobile in the subsurface by the introduction of steam, carbon dioxide, or by using subterranean fire
well-integrity (failure) issues	the well casing and/or its cement seal becoming damaged due to heat or pressures of the underground environment or by the action of the potentially corrosive materials flowing through the well

Acronyms and Abbreviations

Acronym	Full Term
API	American Petroleum Institute
BLM	Bureau of Land Management
BTEX	Benzene, Toluene, Ethylbenzene, and Xylene; volatile aromatic compounds typically found in petroleum products such as gasoline and diesel fuel.
CAA	Clean Air Act
CBM	Coalbed methane
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
COGA	Colorado Oil and Gas Association
CWA	Clean Water Act of 1977
DEHP	di(2-ethykhexyk)phthalate
DOE	U.S. Department of Energy
DRBC	Delaware River Basin Commission
E&P	Exploration and production processes
EIA	U.S. Energy Information Administration
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
EPAct	Energy Policy Act of 2005
ERG	Emergency Response Guidebook
FRAC Act	The Fracturing Responsibility and Awareness of Chemicals Act of 2011
FRESH Act	The Fracturing Regulations are Effective in State Hands Act
FWPCA	Federal Water Pollution Control Act of 1972
IOGCC	Interstate Oil and Gas Compact Commission
NORM	Naturally Occurring Radioactive Materials
NPDES	National Pollutant Discharge Elimination System
NSPS	New Source Performance Standards
PADEP	Pennsylvania Department of Environmental Protection
POTWs	Publicly Owned Treatment Works
ppm	parts per million (a concentration of 1:1,000,000)
RCRA	Resource Conservation and Recovery Act
SDWA	Safe Drinking Water Act
SGEIS	Supplemental Generic Environmental Impact Statement
SRBC	Susquehanna River Basin Commission
TCF	Trillion cubic feet
TDS	total dissolved solids
UIC	Underground Injection Control
USDW	Underground Source of Drinking Water
USGS	U.S. Geological Survey

1. Executive Summary

Although natural gas extraction using hydraulic fracturing has existed for decades, it has seen tremendous growth in recent years as it, along with horizontal drilling, allows oil and gas operators to tap into vast reserves of natural gas in shale rock formations that otherwise would be inaccessible.

Current policies governing natural gas extraction are primarily a mix of private, voluntary efforts and collaboration between federal and state agencies. Simultaneously, calls exist for both more and less government intervention. Currently, there is a lack of objective, science-based information regarding both the potential impacts of natural gas extraction and hydraulic fracturing to water, air, and other environmental media, as well as the long-range impacts of natural gas "booms" to local communities, but basic assumptions and theory can provide a foundation for reasonable discussion of likely impacts.

Maintaining the status quo mix of government policies and free market guidelines will likely continue to limit public cost, but do little to further respond to concerns about the adverse consequences of hydraulic fracturing. Natural gas supplies will continue to expand, limiting energy price increases or even pushing prices down. If those concerns prove unfounded over time, public costs will have been contained and economic development unaffected. However, if concerns prove well-founded, existing policies will be too little too late, possibly resulting in serious, if not irreparable, harm to the environment and possibly leaving bankrupt communities to deal with the boom-bust consequences.

Expanding government intervention will likely increase public cost, limit growth in natural gas supply, and possibly increase the price of energy. If environmental concerns prove unfounded, many will consider the expense a waste and be frustrated at the high opportunity cost. There will also be barriers to economic development; for communities with few options, this could be devastating. However, if the concerns are justified over time, the benefits to the environmental assets protected could be well worth the expense.

Reducing government involvement will save tax dollars and allow natural gas supply to grow, likely resulting in lower energy prices. If concerns are unfounded, there will be few or no adverse impacts to the environment and communities. However, if those concerns are found to be justified, the environmental harm could be irreversible for centuries. The economic benefits to some communities may not justify the losses related to environmental contamination.

If consensus has been found among any of these issues, it is that much more research is needed to objectively and scientifically quantify both the environmental and long-range economic impacts of natural gas development.

2. Introduction to Natural Gas Extraction

The extraction and use of natural gas by humans is not a recent event. Indeed, humans have been using natural gas in one form or another for millennia. What have captured the public's attention in recent years are the changes in *how* natural gas is extracted and used. This section will discuss briefly the history of natural gas before exploring the current techniques used to extract natural gas and the uses of natural gas today. The section concludes with a framing of the natural gas issue.

2.1. A Brief History of Natural Gas

Natural gas, like many other fossil fuels, comes from the transformation of organic materials over millions of years. Most natural gas is formed from the remains of tiny plants and animals that died and accumulated in thick layers at the bottoms of ancient seas. Over time, layers of sand, silt, and other inorganic materials accumulated on top of these remains. As more and more materials piled on top of these layers, incredible pressures and temperatures developed. Over time, these pressures and temperatures converted the organic material into what we now refer to as hydrocarbons, such as coal, oil, and natural gas. Similarly, these pressures also transformed the inorganic material above them into rock, which trapped the hydrocarbons beneath them.[1]

Occasionally, cracks would develop in these rock formations, allowing the hydrocarbons to reach the surface. Historians believe the first natural gas seeps were discovered in Iran between 6000 and 2000 B.C., where lightning strikes likely started the "eternal fires" that gave rise to the fire-worship of the ancient Persians.[2] As early as 900 B.C., natural gas was harvested and used in China, where the first wells dug specifically to obtain natural gas were dug around 200 B.C.[3]

North America's first natural gas well came in 1821 in Fredonia, New York.[4] While natural gas use slowly expanded, petroleum operators still considered natural gas a relatively worthless by-product of oil production to be disposed of rather than collected and used.[5] Gradually, though, more and more uses for natural gas appeared. The first widespread use of natural gas was for street lamps (though coal gas was more prevalently used), but Robert Bunsen's invention of a burner that mixed natural gas allowed for gas heating for homes and cooking.[6] Slowly in the U.S., as well as in Europe, natural gas pipelines began to appear. With this infrastructure in place, natural gas took its place as an important fuel source during the crude oil shortages of the 1960s and 1970s.[7]

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[1] U.S. Energy Information Administration (EIA), Natural Gas Explained: How Was Natural Gas Formed (2012) *available at* http://www.eia.gov/energyexplained/index.cfm?page=natural_gas_home (last visited September 10, 2012).

[2] Enyclopaedia Britannica, Natural Gas, *available at* http://www.britannica.com/EBchecked/topic/406163/natural-gas/50586/History-of-use, (last visited September 7, 2012.)

[3] *Id.*

[4] U.S. Department of Energy (DOE), The History of Natural Gas, *available at* http://www.fossil.energy.gov/education/energylessons/gas/gas_history.html (last visited September 10, 2012).

[5] Encyclopaedia Britannica, *supra* note 2.

[6] DOE, *supra* note 4.

[7] Encyclopaedia Britannica, *supra* note 2.

Natural gas use in the U.S. has grown fairly steadily since the mid 1980s. Today, it serves as a major energy source in the U.S. In 2011, it accounted for approximately 25 percent of U.S. energy use, with 24.37 trillion cubic feet (TCF) of natural gas consumed.[8]

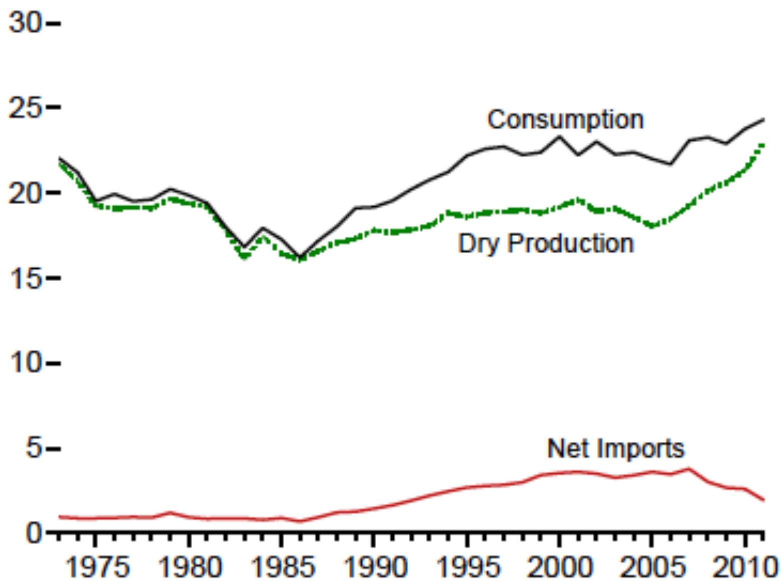

Figure 2-1. U.S. Natural Gas Consumption by year in Trillion Cubic Feet (TCF)[9]

For over a century, the primary use of natural gas has been as a fuel for industrial processes that require large amounts of thermal energy, followed by home and business heating, respectively.[10] Its greatest growth has come from electrical generation, where usage of natural gas has more than doubled between 1990 and 2011.[11] A number of factors including relatively low cost, expansion of natural gas-fueled generating capacity, and relatively low emissions are expected to continue the growth of natural gas as source of electrical generation fuel.[12] Similarly, its use as a transportation fuel continues to rise, with its use more than doubling in the last ten years.[13]

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[8] EIA, NATURAL GAS EXPLAINED: USE OF NATURAL GAS, *available at* http://www.eia.gov/energyexplained/index.cfm?page=natural_gas_use, (last visited September 10, 2012.

[9] Figure source: EIA, MONTHLY ENERGY OVERVIEW, AUGUST 2012, *available at* http://www.eia.gov/totalenergy/data/monthly/#naturalgas, (last visited September 10, 2012).

[10] EIA, EIA MONTHLY ENERGY OVERVIEW, AUGUST 2012, *available at* http://www.eia.gov/totalenergy/data/monthly/#naturalgas (last visited September 10, 2012).

[11] *Id.*

[12] *See, e.g.* EIA, NATURAL GAS DEMAND AT POWER PLANTS WAS HIGH IN SUMMER 2012, *Today in Energy*, September 7, 2012, available at http://www.eia.gov/todayinenergy/detail.cfm?id=7870 (last visited September 10, 2012); U.S. ENVIRONMENTAL PROTECTION AGENCY (EPA), CLEAN ENERGY: NATURAL GAS, *available at* http://www.epa.gov/cleanenergy/energy-and-you/affect/natural-gas.html (last visited September 10, 2012).

[13] EIA, U.S. NATURAL GAS VEHICLE FUEL CONSUMPTION, *available at* http://www.eia.gov/dnav/ng/hist/n3025us2A.htm (last visited September 10, 2012).

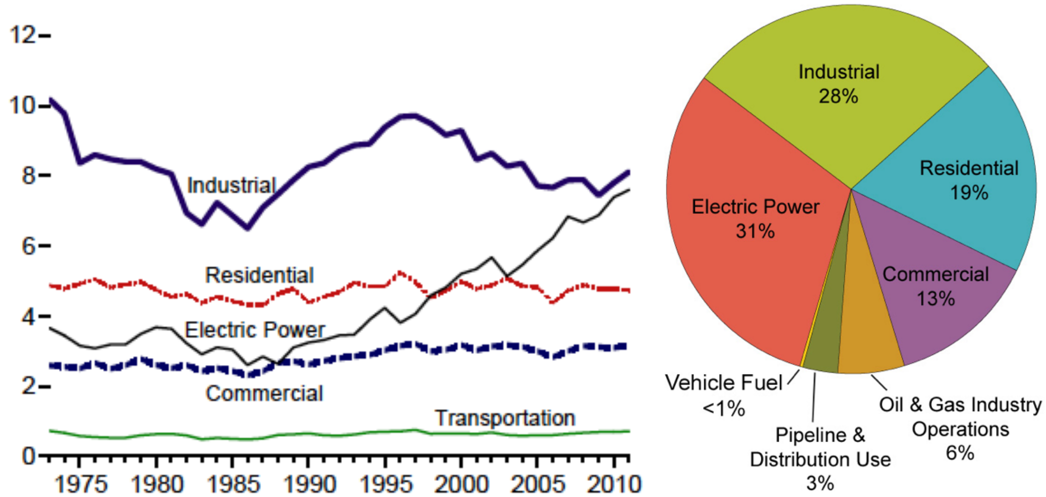

Figure 2-2. Natural Gas Consumption by Sector, Time-series (TCF) and 2011 Snapshot[14]

2.2. Natural Gas Extraction Today

Society's increasing energy needs have led oil and gas operators to constantly seek new technologies for extracting resources. The two technologies responsible for the significant growth of natural gas production in recent years – directional (sometimes called "horizontal") drilling and hydraulic fracturing (sometimes called "fracing" or "fracking") – have actually been in use for decades. Relatively recent breakthroughs in these technologies made tremendous differences in their application, though, and made development of several more natural gas resources an economic possibility.

2.2.1. Traditional Vertical Well Development

The processes discussed in section 2.1 above creates deposits of oil and natural gas in geologic formations distributed throughout the world. Some of these deposits occur so close to the surface that they actually seep out of the ground, like the deposits of gas tapped in Fredonia, New York, or the oil seeps of Titusville, Pennsylvania, that led to the first U.S. oil well.[15] More commonly, though, operators must drill wells hundreds or thousands of feet beneath the surface to reach formations that have trapped significant amounts of oil and/or natural gas.

The use of the word "trapped" is significant. Oil and gas start out in the geologic formations that created them (sometimes called "source rock"), but over time, the water that was in the sediments forming the oil and gas may displace those hydrocarbons.[16] Since the oil and gas molecules are lighter than water, they are buoyant. This buoyancy and other geologic pressures force the oil and gas upward through the pore spaces in the surrounding rock.[17] If they do not encounter any other obstacles, the oil and gas eventually find their way to the surface and form seeps. In many other cases, though, they encounter a less permeable geologic formation (that is, the rock is less porous) that stops the oil and gas

[14] Figure source: EIA, *supra* note 10.
[15] MARTIN S. RAYMOND AND WILLIAM L. LEFFLER, OIL AND GAS PRODUCTION IN NONTECHNICAL LANGUAGE, 1 (2006).
[16] *See id.* at 44, 57.
[17] *Id.* at 44.

from moving either laterally or vertically.[18] This area forms a "trap" where the oil and gas accumulate. It should be noted that the water that helped force the oil and gas upward will likely inhabit the same formation, meaning that production of oil and gas will likely also produce some of this water. This water frequently contains high levels of dissolved minerals from the surrounding rock, and is often called "saltwater" or "brine."[19]

Generally, the oil and gas industry works to locate these traps because they represent the easiest and, therefore, the most economic sources of the resource. To locate these traps, operators frequently use seismic exploration. Seismic exploration directs waves of sound energy into the ground and uses sensors to record the reflection of those sound waves off of the subsurface rock layers.[20] By measuring the differences in these reflections, petroleum geologists can visualize the shape of the formations and locate areas likely to contain oil and gas traps.[21] Different techniques may be used to generate the sound based on the local conditions. In some cases, holes may be dug between 60 and 100 feet deep to place explosives into the bedrock. These explosives are then detonated to generate the sound waves used for seismic data.[22] In other situations, a large truck (sometimes called a "vibrator" or "thumper truck") will use hydraulic rams and the weight of the truck to generate the vibrations needed to generate the seismic data.[23]

Once seismic surveying identifies an area likely to hold oil and gas deposits, those deposits must be reached by an oil and gas well. Rotary drilling rigs create most oil and gas wells today. A modern rotary drilling rig contains numerous components that allow it to assemble the drill stem, bore the well, remove the drilled material from the well, and assemble the casings that make up the final construction of the well. Since a rig must drill a well and then move on to another location, the components of the rig and its supporting equipment can be trucked to a wellsite, assembled, and then disassembled and transported to another site.[24] Thus, assembling and disassembling a rig will involve numerous truck trips to the wellsite.

To drill an oil or gas well (a "make hole" in the language of the industry), the operator attaches a "bit" that will cut, gouge, or break up the rock in the formations below the rig to a length of pipe called the "drill string." A "turntable" on the rig rotates the bit and drill string to create the drilling action. As the bit digs deeper and deeper, the operator uses the rig to attach additional lengths of drill string to continue making the drill longer.[25]

Conditions for the drill bit are harsh. The action of drilling creates debris that must be removed from the well. Drilling also generates high temperatures for the bit. Additionally, at the depth of some wells – often thousands of feet deep – the surrounding formations themselves generate tremendous pressures and temperatures. For this purpose, the hollow drill string allows the operator to circulate a material called "drilling mud" down the string, through the drill bit, and back up to the surface of the well. Despite its name,

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[18] *Id.* at 44.
[19] *Id.* at 57.
[20] NORMAN J. HYNE, NONTECHNICAL GUIDE TO PETROLEUM GEOLOGY, EXPLORATION, DRILLING, AND PRODUCTION, 213 (2001).
[21] *Id.*
[22] *Id.* at 214.
[23] *Id.*
[24] RAYMOND & LEFFLER, *supra* note 15 at 96.
[25] *See id.*

drilling mud is not simply water and dirt; rather, it is a carefully formulated mixture of components designed to give it very specific properties of density and viscosity as well as allowing it to serve a number of functions in the creation of the well.[26] Drilling mud has several key purposes. These functions include creating internal pressure on the borehole to counteract the pressure of the surrounding geologic formation; to lubricate and cool the drill bit, and to lift the drill cuttings out of the borehole.[27] Once the mud returns to the surface, it is processed to remove the drill cuttings and recycled until it loses its usefulness.[28] These drill cuttings include all of the materials removed from the wellbore and can include a wide variety of minerals and other substances. Operators frequently store spent mud, drill cuttings, and salt water produced form the well in a large earthen pit called a "reserve pit."[29] Eventually, the operator must dispose of the materials stored in the reserve pit or close the pit to permanently contain the materials.

To reach the targeted formation, the drill may pass through a number of formations including aquifers that contain freshwater, saltwater formations, and other geologic strata. Without further action by the operator, the wellbore could create the opportunity for saltwater, hydrocarbons, or other materials to travel through it and mix with the freshwater, thereby contaminating it. Thus, once the operator reaches his or her desired depth, a decision must be made – whether to "complete" the well or to "plug" it.

If the well appears capable of producing enough oil and/or gas to justify the cost, the operator will "complete" the well by installing casing.[30] Several types off casing will be used to create the final structure of the well, enabling the well to withstand the pressures acting on it and prevent the mixing of substances from the formations penetrated by it. The first casing, called "conductor" casing serves as a foundation and guide for the casings to follow.[31] Next, the operator installs "surface" casing. Surface casing serves a crucial function; it must be installed to a depth below the deepest source of freshwater encountered by the well and must be surrounded by cement to seal both the well and the freshwater-containing formation apart from each other.[32] In some wells, "intermediate" casing may follow the surface casing.[33] Finally, "production" casing forms the remainder of the well down to its final depth. After placing all casing, the operator will pump cement down through the casing and out the end of the casing, causing it to flow back up the well around the outside of the casing (the space between the casing and the sides of the well is sometimes called the "annulus") until it reaches the surface again.[34] This process seals off the formations encountered by the well to prevent leaking of substances from the formations and any pollution that could be caused by such leaking.[35] Given the importance of this function, and the immense stresses placed on the well, the concrete used must be carefully formulated and installed.[36]

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[26] *Id.*
[27] *Id.*
[28] *Id.* at 100.
[29] HYNE, *supra* note 20 at 239.
[30] RAYMOND & LEFFLER, *supra* note 15 at 139.
[31] HYNE, *supra* note 20 at 241.
[32] EPA OFFICE OF RESEARCH AND DEVELOPMENT, PLAN TO STUDY THE POTENTIAL IMPACTS OF HYDRAULIC FRACTURING ON DRINKING WATER RESOURCES," 14 (2011).
[33] *Id.*
[34] RAYMOND & LEFFLER, *supra* note 15 at 140-141.
[35] *Id.*
[36] EPA, *supra* note 32 at 15.

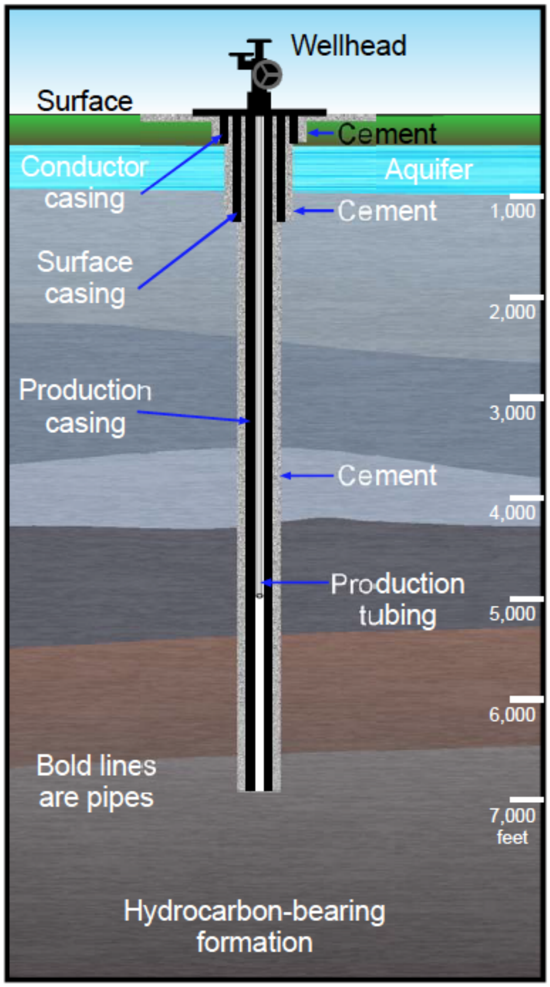

Figure 2-3. Well Casing Diagram[37]

If the well seems uneconomic to produce, it will be "plugged." After removing any casing already in place, the operator will install a series of concrete plugs at specific depths to seal off any zones at risk of leaking substances that could contaminate groundwater, including a plug at the base of the lowest depth of freshwater. [38]

2.2.2. Horizontal Drilling

To this point, the discussion has focused on the development of a traditional vertical well. Such wells can only extract oil or gas from the portion of the well that intersects the hydrocarbon-bearing formation. As a result, operators sought formations that were highly "permeable" and thus allowed the oil or gas to flow to the end of the wellbore. Conversely, formations that were not highly permeable did not allow oil or gas to be recovered in amounts that justified the cost of drilling and completing the well.

Advancements in horizontal drilling technology changed the situation, though. With horizontal drilling, the wellbore direction can now follow along a formation for a significant

[37] Figure source: EPA, *supra* note 32.
[38] RAYMOND & LEFFLER, *supra* note 15 at 448-449; EPA, *supra* note 32 at 16.

length. This exposes a much greater portion of the wellbore to the formation than a traditional vertical well would allow. [39] A horizontal well in the Marcellus shale of Pennsylvania may intercept 2,000 to 6,000 feet of formation where a vertical well could only intercept 50 feet.[40]

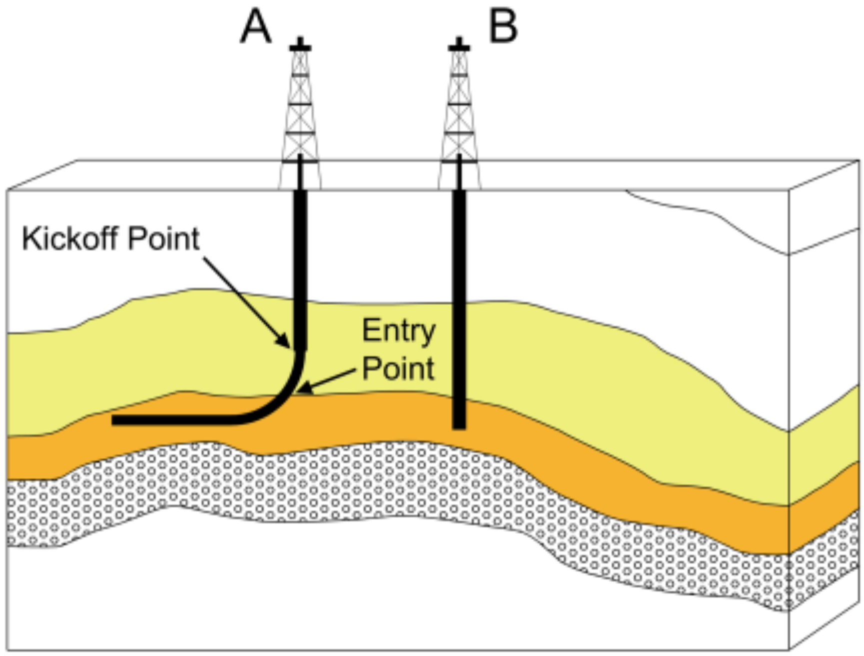

Figure 2-4. Comparison of Vertical and Horizontal Wells[41]

Operators have had the capability of drilling wells at a non-vertical angle for decades.[42] These wells, sometimes called "deviated" or "slant" wells were sometimes used to access formations that could not be accessed by a vertical well such as formations beneath water or other environmentally sensitive sites, or sites that were too rugged to reach.[43] However, recent advancements in drilling technology have allowed operators to have much greater control in directing the drill bit.[44] This allows operators to reach horizontal distances of nearly five miles from the well pad.[45] Horizontal drilling also allows for eight or more wells to be drilled from a single well pad, allowing a given parcel of land to be developed by a much smaller number of surface well pads than if vertical wells were used.[46] Horizontal wells generally require more time and expense to complete than a traditional vertical well.[47]

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[39] DOE OFFICE OF FOSSIL ENERGY AND NATIONAL ENERGY TECHNOLOGY LABORATORY, MODERN SHALE GAS DEVELOPMENT IN THE UNITED STATES: A PRIMER, ES-3 (2009), *available at* http://www.netl.doe.gov/technologies/oil-gas/publications/epreports/shale_gas_primer_2009.pdf (last visited September 26, 2012).
[40] *Id.* at 47.
[41] Figure Source: Lynn Helms, *Horizontal Drilling*, North Dakota Department of Mineral Resources Newsletter, March, 2008 at 1, *available at* https://www.dmr.nd.gov/ndgs/newsletter/NL0308/pdfs/Horizontal.pdf (last visited September 27, 2012).
[42] RAYMOND & LEFFLER, *supra* note 15 at 16.
[43] HYNE, *supra* note 20 at 281-282.
[44] For a more detailed discussion of these technologies and the techniques used to direct and survey the wellbore in horizontal drilling, *see* HYNE, *supra* note 20 at 285-294.
[45] *See, e.g.* Thomas M. Redlinger and John McCormick, *Longer, Deviated Wells Push Drill Pipe Limits,* DRILLING CONTRACTOR, March, 2011, *available at* http://www.drillingcontractor.org/longer-deviated-wells-push-drill-pipe-limits-8779 (last visited September 12, 2012).
[46] *See* DOE, *supra* note 39 at 47-48.
[47] RAYMOND & LEFFLER, *supra* note 15 at 16.

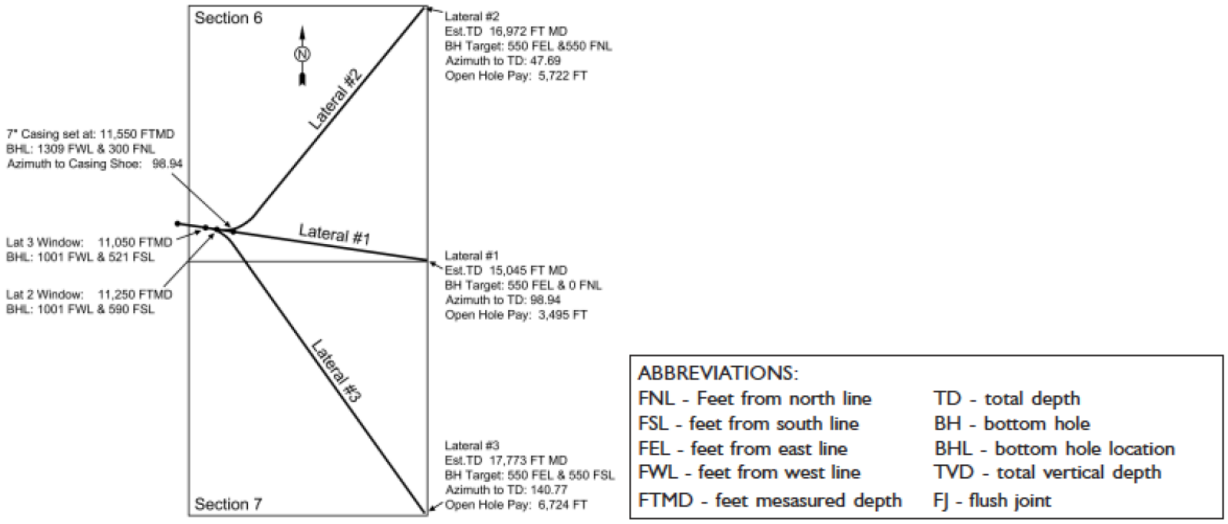
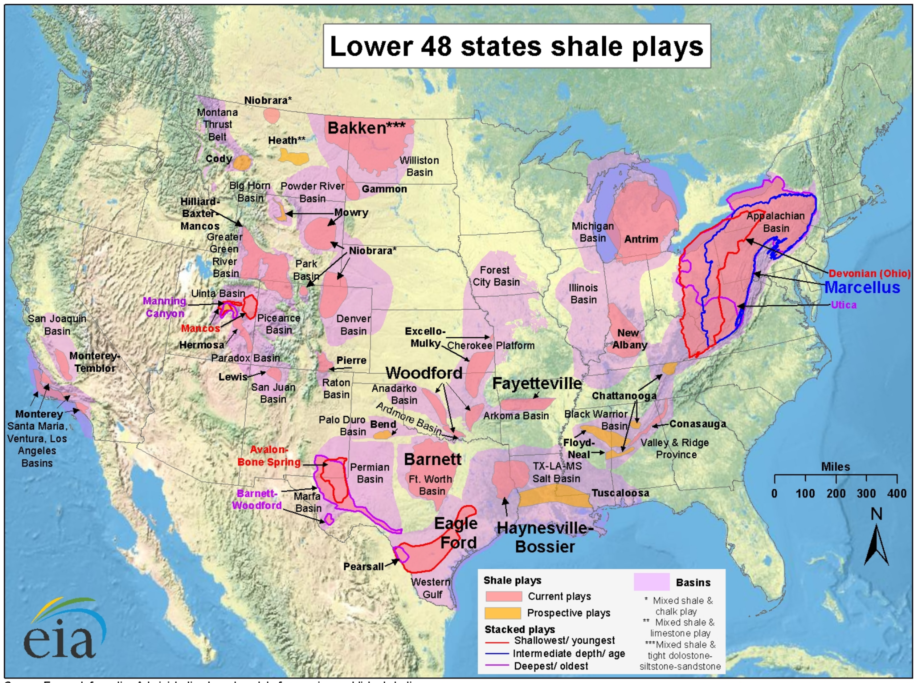


Figure 2-5. Sample Horizontal Drilling Plan[48]

2.2.3. Hydraulic Fracturing

Horizontal drilling allows operators to expose a much greater area of the wellbore to the hydrocarbon-containing formation, but even that exposure will not produce the desired flow of oil or gas if the formation does not permit the oil and gas molecules to migrate through the formation and into the wellbore. This issue kept operators from tapping into the significant reserves of natural gas contained in shale formations. Shale rock's tight formations, in their natural state, frequently lack the pathways that allow a well to collect oil and gas economically. That is where hydraulic fracturing makes the difference.

[48] Figure Source: Helms, *supra* note 41 at 3.



Source: Energy Information Administration based on data from various published studies.
Updated: May 9, 2011

Figure 2-6. Shale Gas Plays in the Lower 48 States[49]

Hydraulic fracturing was first used in the 1940's.[50] Traditionally, wells that were near the end of their useful life were hydraulically fractured to stimulate the last remaining production from them. Fracturing fluid (composed primarily of water) was forced down the well at high pressures to exploit weaknesses in the hydrocarbon-containing formation, opening cracks in the formation that would allow for an improved flow of oil and gas into the well.[51] Hence, the term "hydraulic fracturing."

[49] Figure Source: EIA, Natural Gas: Maps: Exploration, Resources, Reserves, and Production, *available at* http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/maps/maps.htm (last visited September 27, 2012).
[50] HYNE, *supra* note 20 at 560.
[51] *Id.* at 422-423.

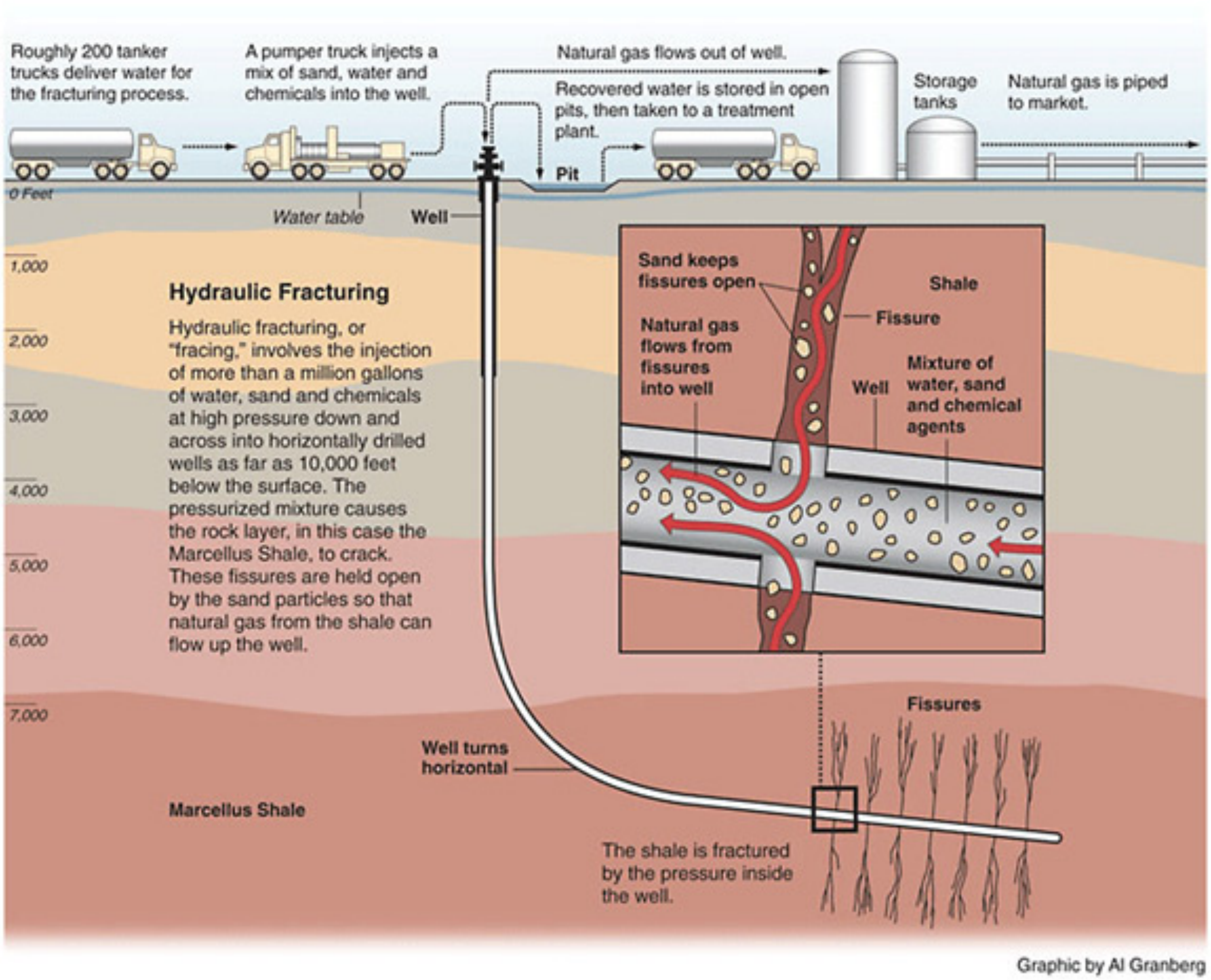


Figure 2-7. Hydraulic Fracturing Process[52]

Modern hydraulic fracturing involves very precise seismic surveys of the formation to be fractured to determine the amount, composition, and pressure of fracturing fluid necessary to create fractures in the right rock formation.[53] Water remains the primary component of most fracturing fluids, though some fluids are petroleum-based. Water provides a virtually incompressible fluid to generate pressure against the hydrocarbon-containing rock, give the fluid volume, and serve as a carrier to transport the other materials. In some cases, diesel fuel may be used instead of water to modify the physical properties of the fluid (such as the fluid's viscosity or lubricity) or to serve as a solvent for other fluid components.[54] Fracturing fluids also contain "proppant," so called because it consists of particles (frequently sand, though ceramic beads or other spherical materials may be used) forced into the fractures to hold ("prop") them open, allowing oil or gas to flow through them.[55] Fracturing fluid often contains numerous other substances with a wide variety of functions, as shown in Table 2-1 below.

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[52] Figure Source: EIA, WHAT IS SHALE GAS AND WHY IS IT IMPORTANT, available at http://www.eia.gov/energy_in_brief/about_shale_gas.cfm (last visited September 27, 2012).
[53] DOE, *supra* note 39 at 56.
[54] EPA, UNDERGROUND INJECTION CONTROL (UIC) PROGRAM PERMITTING GUIDANCE FOR OIL AND GAS HYDRAULIC FRACTURING ACTIVITIES USING DIESEL FUELS, UIC PROGRAM GUIDANCE #84 – DRAFT, *available at* http://water.epa.gov/type/groundwater/uic/class2/hydraulicfracturing/upload/hfdieselfuelsfs.pdf (last visited September 18, 2012).
[55] *Id.*

Table 2-1. Common Components of Hydraulic Fracturing Fluid[56]

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

Hydraulic fracturing requires significant amounts of water, frequently ranging between 2 and 4 million gallons or more to complete a well.[57] Operators may use surface water from

[56] Table source: DOE, *supra* note 39 at 63.
[57] *Id.* at 64.

streams, rivers, ponds, and lakes if they are available; groundwater wells may provide water if no surface water is available.[58]

Once the fracturing fluid is formulated, the operator injects it at high pressures into the targeted formation. This operation may take a number of fracturing trucks working together to generate the fluid pressures and volumes needed.[59] After the fractures form, the operator releases the pressure on the well. This allows some of the fracturing fluid to return to the surface (though the amount of this fluid, sometimes called "flowback" can vary greatly depending on the formation). The operator may recycle this flowback for subsequent hydraulic fracturing operations.[60] Wells may also produce salt water in the targeted formation (this water may be called "produced water") that can contain minerals and gases associated with the formation beyond natural gas and oil. When flowback and produced water cannot be reused in the well, the operator must find a way to dispose of the water. Options for disposal include injecting the water in an underground disposal well, treating the water and releasing it to a nearby water body, applying the water to land, or disposing of it through a nearby waste water treatment plant.[61]

2.2.4. Production and Transportation of Gas

Natural gas extracted from the well must get to market. Typically, operators will use pipelines to connect gas wells to a central facility that may remove any remaining water from the gas in a process called "dehydration," often accomplished by bubbling the gas through a material that will absorb the water (such as ethylene glycol).[62] "Sweetening" units may remove corrosive gases such as carbon dioxide and hydrogen sulfide.[63] Once the gas meets the requirements to be shipped to buyers by pipeline, large compressors bring the gas to the pressure needed to move the gas through the pipeline. These compressors may be powered by natural gas, electricity, or diesel.[64]

2.2.5. Local Impacts

As demonstrated by this discussion, natural gas production involves a great number of processes. In areas experiencing a great deal of natural gas exploration and production, this may mean that large numbers of workers and significant quantities of supplies are needed. This need can trigger economic impacts in both the local community and the region at large. As an example, natural gas development in the Marcellus Shale of Pennsylvania has been estimated to create anywhere from 10,000 to 140,000 jobs.[65]

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[58] EPA, *supra* note 32 at 23.
[59] *See* HYNE, *supra* note 20 at 425.
[60] EPA, *supra* note 32 at 23.
[61] EPA, *supra* note 32 at 43, 49, 81.
[62] *See* HYNE, *supra* note 20 at 369.
[63] *Id.*
[64] *See id.* at 370.
[65] *See* note 246 *infra*.

3. Issue Background

The rapid expansion of the natural gas industry has generated vigorous discussion across a broad spectrum of stakeholders. The breadth of the concerns voiced in the debate mirrors the diversity of those involved. Topics in the natural gas conversation range from environmental ipacts to stresses on "boomtown" communities, with everyone from the President of the United States to documentarians weighing in on the issue. Section 3 lays out some of the most common concerns associated with natural gas extraction and provides research-based background for these issues. This information creates a foundation for discussion of the policy options presented in Section 4.

3.1 Water Quality Issues

Stakeholders frequently express concern regarding the impact of natural gas extraction activities on the quality of water resources. Some worry that the hydraulic fracturing process could introduce harmful chemical constituents into groundwater resources or that substances associated with natural gas extraction could reach surface water resources. Additionally, many stakeholders worry about what chemicals hydraulic fracturing fluids introduce into the environment.

These concerns gathered enough public attention to prompt Congress to action. In 2009, Congress directed the U.S. Environmental Protection Agency (EPA) to conduct a rigorous study of the relationship between hydraulic fracturing and drinking water.[66] In preparing a plan of study for the issue, EPA identified the following five over-arching issues that could link hydraulic fracturing to water impacts:[67]

1. Water Acquisition: What are the potential impacts of large volume water withdrawals from ground and surface waters on drinking water resources?
2. Chemical Mixing: What are the possible impacts of surface spills on or near well pads of hydraulic fracturing fluids on drinking water resources?
3. Well Injection: What are the possible impacts of the injection and fracturing process on drinking water resources?
4. Flowback and Produced Water: What are the possible impacts of surface spills on or near well pads of flowback and produced water on drinking water resources?
5. Wastewater Treatment and Waste Disposal: What are the possible impacts of inadequate treatment of hydraulic fracturing wastewaters on drinking water resources?

EPA estimates a 2014 completion of its report, with a preliminary report due in late 2012.[68] When completed, the study will represent the largest and most comprehensive effort to date created to objectively evaluate the environmental impacts of natural gas extraction. In the meantime, the discussion regarding groundwater, surface water, and fracturing fluids impacts continues and must use the existent base of research information and expert opinion based on sound scientific theory.

[66] DEPARTMENT OF THE INTERIOR, ENVIRONMENT, AND RELATED AGENCIES APPROPRIATIONS ACT, 2010, H.R. 2996, 111th Cong. (enacted) Conf. Comm. Report, *available at* http://www.gpo.gov/fdsys/pkg/CRPT-111hrpt316/pdf/CRPT-111hrpt316.pdf (last visited September 14, 2012).
[67] EPA, *supra* note 32 at ix.
[68] EPA, EPA'S STUDY OF HYDRAULIC FRACTURING AND ITS POTENTIAL IMPACT ON DRINKING WATER RESOURCES, *available at* http://www.epa.gov/hfstudy/index.html (last visited September 12, 2012).

3.1.1. Groundwater Issues

Perhaps no issue related to natural gas extraction has garnered as much attention, debate, and emotion as the potential impacts it may have on groundwater resources. Concern about these impacts was one of the primary causes leading to the state of New York's moratorium on hydraulic fracturing activities.[69] Concerns regarding hydraulic fracturing's impacts to water were also cited in a temporary moratoria placed on the practice in New Jersey[70] and by the Delaware River Basin Commission.[71] Numerous other county and municipal jurisdictions have imposed such moratoria (though the enforceability of those moratoria are in question given the delegation of powers between states and their sub-units in each case).[72] Individuals and groups both opposed to and in favor of hydraulic fracturing have made water quality issues a focus of the debate. National attention was further focused on the issue with the release of the 2010 film *Gasland*, which showed a Dimock, Pennsylvania, resident igniting methane-saturated tap water from his kitchen sink.[73]

While a host of issues arise concerning the potential effects of hydraulic fracturing on groundwater, most of the discussion focuses on two potential pathways for groundwater contamination. The first focuses on the fracturing process creating cracks in geologic formations, allowing either hydraulic fracturing fluids or hydrocarbons to migrate into fresh groundwater formations. The second focuses on the potential discharge of hydraulic fracturing fluids or hydrocarbons through breaches in the natural gas well as it passes through fresh groundwater formations.

3.1.1.1. Jurisdiction over hydraulic fracturing operations

To discuss which government entities hold jurisdiction over hydraulic fracturing operations, one must define "hydraulic fracturing" for that purpose. As used in this subsection, "hydraulic fracturing" will mean the process of injecting fluids into a geologic formation to cause the fracturing of that formation. A narrow definition is required because the oil and gas extraction process involves many other aspects that may involve a host of other jurisdictions. Further, research indicates that the public does not separate the hydraulic fracturing process from other elements of oil and gas production, and this may lead to confusion in public deliberation.[74]

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[69] *See e.g.* NEW YORK DEPARTMENT OF ENVIRONMENTAL CONSERVATION, MARCELLUS SHALE, *available at* http://www.dec.ny.gov/energy/46288.html (last visited September 14, 2012), noting that "Most concerns are related to water use and management and the composition of the fluids used for fracturing the shale." Governor Paterson's Executive Order 41 on December 13, 2010 served as a moratorium on drilling until the state completed its final Supplemental Generic Environmental Impact Statement (SGEIS) for Oil, Gas and Solution Mining Regulatory Programs. As of this writing, the final SGEIS has not been completed. For a copy of Executive Order 41, see http://www.governor.ny.gov/archive/paterson/executiveorders/EO41.html, last visited September 15, 2012.

[70] On August 25, 2011, New Jersey Governor Chris Christie conditionally vetoed New Jersey bill S-2576 (which would have permanently banned hydraulic fracturing in the state) to put in place a one-year moratorium on the practice allowing for more study of the environmental issues involved, including water. *See* Press Release, State of New Jersey, Governor's Office, Governor Chris Christie Stands Up for Sound Policymaking by Issuing One-Year Moratorium on Fracking, *available at* http://www.state.nj.us/governor/news/news/552011/approved/20110825c.html, (last visited September 15, 2012).

[71] The Delaware River Basin Commission (DRBC) effectively placed a temporary moratorium on hydraulic fracturing within its jurisdiction until it could promulgate rules to address the issue at its May 5, 2010 meeting. *See* Delaware River Basin Commission Meeting of May 5, 2010, p. 4-5, *available at* http://www.state.nj.us/drbc/library/documents/5-05-10_minutes.pdf (last visited September 15, 2012).

[72] For maps and listings of county and municipal moratoria on fracking, *see* FrackTracker, available at http://www.fractracker.org/fractracker-maps/ny-moratoria/ (last visited September 20, 2012).

[73] HBO Documentary Films and International WOW Company, *Gasland* (motion picture, released 2010).

[74] MARY TIEMANN AND ADAM VANN, CONG. RES. SERV., R41760, HYDRAULIC FRACTURING AND SAFE DRINKING WATER ACT ISSUES, 14 (2012), *available at* http://www.fas.org/sgp/crs/misc/R41760.pdf (last visited September 26, 2012), *citing* HEATHER COOLEY AND KRISTINA

The Underground Injection Control Program established by the Safe Drinking Water Act (SDWA)[75] first comes to mind for many people when discussing the injection of fluids into geologic formations. The SDWA regulates such injections through the Underground Injection Control Program (UIC) that, among other goals, seeks to protect underground sources of drinking water (USDWs)[76] from contamination. Under the SDWA, states may administer programs that regulate the operation of wells that inject fluids into underground geologic formations;[77] alternatively, EPA will administer such programs in states that choose not to accept the delegation of that authority.[78]

The UIC program covers five classes of injection wells:[79]

Table 3-1. Classes of UIC Wells[80]

Well Class	Description	Example
Class I	Inject hazardous wastes, industrial non-hazardous liquids, or municipal wastewater beneath the lowermost USDW	Liquid hazardous waste disposal well
Class II	Inject fluids brought to the surface in connection with conventional oil or natural gas production for enhanced recovery of oil or natural gas; and for storage of hydrocarbons which are liquid at standard temperature and pressure	Saltwater disposal well, natural gas storage well
Class III	Inject fluids associated with solution mining of minerals beneath the lowermost USDW	Extraction of uranium in solution
Class IV	Inject hazardous or radioactive wastes into or above USDWs (These wells are banned unless authorized under a federal or state ground water remediation project.)	Generally prohibited
Class V	All injection wells not included in Classes I-IV. In general, Class V wells inject non-hazardous fluids into or above USDWs and are typically shallow, on-site disposal systems. However, there are some deep Class V wells that inject below USDWs.	Geothermal electric power well
Class VI	Inject Carbon Dioxide (CO2) for long term storage, also known as Geologic Sequestration of CO2	Power plant carbon dioxide storage well

DONNELLY, PACIFIC INSTITUTE, HYDRAULIC FRACTURING AND WATER RESOURCES: SEPARATING THE FRACK FROM THE FICTION, 29 (2012), *available at* http://www.pacinst.org/reports/fracking/ .

75 42 U.S.C. §§ 300f – 300j26 (2012).

76 An "underground source of drinking water" is defined by the UIC regulations as "an aquifer or its portion: Which supplies any public water system; or which contains a sufficient quantity of ground water to supply a public water system; and currently supplies drinking water for human consumption; or contains fewer than 10,000 mg/l total dissolved solids; and which is not an exempted aquifer." 40 C.F.R. § 144.3 (internal formatting omitted).

77 42 U.S.C. § 300h-1(b) (2012).

78 42 U.S.C. § 300h-1(c) (2012).

79 40 C.F.R. § 146.5 (2012).

80 Table data source: Source: 40 C.F.R. § 146.5 (2012) and EPA, CLASSES OF WELLS, *available at* http://water.epa.gov/type/groundwater/uic/wells.cfm (last visited September 21, 2012).

While other classes of wells may come into play, Class II wells represent the vast majority of UIC wells involved in the oil and gas industry.

The SDWA includes specific language dealing with Class II wells:[81]

> Regulations of the Administrator under this section for state underground injection control programs may not prescribe requirements which interfere with or impede—
> (A) the underground injection of brine or other fluids which are brought to the surface in connection with oil or natural gas production or natural gas storage operations, or
> (B) any underground injection for the secondary or tertiary recovery of oil or natural gas,
> unless such requirements are essential to assure that underground sources of drinking water will not be endangered by such injection.

Effectively, this language places most Class II wells outside the reach of federal regulations, leaving states to regulate such wells. However, the phrase "injection for the secondary or tertiary recovery of oil or natural gas" caused some controversy as hydraulic fracturing began to grow rapidly. Some parties argued that this language prohibited the regulation of hydraulic fracturing wells, since they engaged in the *primary*, rather than *secondary or tertiary* recovery of oil or natural gas.[82] After a federal appeals court ruled that hydraulic fracturing to extract coalbed methane (CBM) did not fit within the Class II exception and, thus, had to be regulated by EPA, Congress modified the definition of the term "underground injection." Language in section 322 of the Energy Policy Act of 2005[83] (EPAct) created the new definition:[84]

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

Effectively, the EPAct language excluded hydraulic fracturing wells from EPA jurisdiction unless the well uses diesel fuel as a hydraulic fracturing fluid. As a result, state regulatory agencies serve as the primary regulators of the hydraulic fracturing process. Debate on this issue continues in Congress. The Fracturing Responsibility and Awareness of

[81] 42 U.S.C. §300h(b)(2) (2012).
[82] "Secondary recovery" as used in the oil and gas industry is commonly understood to mean the injection of water in to a hydrocarbon bearing formation to increase the pressure on the formation and drive additional oil or gas toward the wellbore. "Tertiary recovery" typically involves efforts to reduce the viscosity of oil or to make it more mobile in the subsurface by the introduction of steam, carbon dioxide, or by using subterranean fire. *See* RAYMOND & LEFFLER, *supra* note 15 at 176-186.
[83] Pub. L. 109-58.
[84] The new definition is codified at 42 U.S.C. § 300h(d) (2012).

Chemicals Act of 2011 (FRAC Act),[85] would reverse the changes made to the definition of "underground injection" made by the EPAct and would revise the definition to include "the underground injection of fluids or propping agents pursuant to hydraulic fracturing operations related to oil, gas, or geothermal production activities."[86] This would essentially require regulation of hydraulic fracturing wells by either the states or by EPA (depending on the delegation of SDWA authority in each state), and would allow EPA to promulgate requirements for such wells. Until this bill is passed, though, primary authority for regulating hydraulic fracturing activity rests with the several states, and this section will discuss these state regulations in their various contexts.

3.1.1.2. Concerns Regarding Breaches in Geological Formations

In its report "Hydraulic Fracturing and Safe Drinking Water Act Issues," the Congressional Research Service succinctly summarized the debate surrounding the first issue:

> A particularly contentious issue concerns whether the fracturing process could create or extend fractures linking the producing zone to an overlying aquifer and, thus, provide a pathway for gas or fracturing fluids to migrate. In shale formations, the vertical distance separating the target zone from usable aquifers generally is much greater than the length of the fractures induced during hydraulic fracturing. Thousands of feet of rock layers typically overly the produced portion of the shale, and these layers serve as barriers to flow. Consequently, regulators and geologists generally view as remote the possibility of creating a fracture that reaches a potable aquifer. However, if the shallow portions of shale formations were developed, then the thickness of the overlying rocks would be less and the distance from the shale to potable aquifers would be shorter, posing more of a risk to groundwater.[87]

The level of risk to a particular fresh groundwater formation seems to relate, at least in part, to the geology of the region. Depending on that geology, fresh groundwater formations and natural gas shale formations may range in separation from a hundred feet to thousands.

Table 3-2. Separation of Shale Formations and Groundwater Sources[88]

Gas Shale Basin	**States**	**Rock Column Thickness between Top of Play and Bottom of Treatable Water, ft.**
Barnett	TX	5,300 – 7,300
Fayetteville	AR	500 – 6,500
Haynseville	LA, TX	10,100 – 13,100
Marcellus	NY, PA, OH, VA, WV	2,125 – 7,650
Woodford	OK, TX	5,600 – 10,600
Antrim	MI	300 – 1,900
New Albany	IL, IN, KY	100 – 1,600

[85] H.R. 1084, S. 587.
[86] TIEMANN AND VANN, *supra* note at 22, *citing* H.R. 1084 at §2(a).
[87] *Id.* at 4.
[88] Table data source: DOE, *supra* note 39 at 17.

Operators typically engage in extensive study of the local geology and use sophisticated modeling techniques to carefully plan the fracturing program for a well.[89] Strong economic incentives drive this preparation, because causing fractures to extend beyond the targeted formation can cause a host of production problems, up to and including the loss of the well.[90] Even with such preparation, fracture lengths can differ from predictions, raising concerns that even the most carefully-crafted fracture program could create pathways allowing for hydrocarbons or fracturing fluids to mix with fresh groundwater sources.[91] Naturally, greater concern accompanies geologies with the least separation between the two strata of interest. As an example, the Ground Water Protection Council (GWPC) reported incidents of groundwater contamination linked to hydraulic fracturing of coalbed methane formations relatively close to, or coexisting with, fresh groundwater formations.[92] At the same time, though, some claims of water contamination also come from areas with much greater separation between formations, though such claims remain unconfirmed.[93]

Complaints from water well users in the Marcellus Shale illustrate both the groundwater pollution concerns and the difficulties in scientifically validating those concerns. Residents of the town of Dimock, Pennsylvania, (featured in the *Gasland* film) noticed a number of drinking water quality issues shortly after the commencement of natural gas drilling in the area. An initial assessment of local water wells by the Pennsylvania Department of Environmental Protection (PADEP) found methane, arsenic, barium, DEHP, glycol, manganese, phenol, and sodium.[94] EPA provided temporary drinking water supplies and began sampling wells in the area.[95] At most of these wells, EPA did not find contaminant levels that would require further agency action, although some wells did show elevated levels of arsenic, barium, and manganese.[96] While EPA noted that these chemicals occurred naturally, the agency made no statement regarding whether the presence of the substances was linked to drilling activity in the area.[97]

EPA also conducted an investigation of groundwater contamination complaints near Pavillion, Wyoming, where hydraulic fracturing occurred at depths both below and within the fresh groundwater formation.[98] In the deep-water monitoring wells installed for the

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[89] DOE, *supra* note 39 at 56-58 (2009).
[90] *Id.* at 58.
[91] *See* EPA, *supra* note 68 at 37, *citing* A. A. Daneshy, *Off-balance Growth: A New Concept in Hydraulic Fracturing* 55:4 JOURNAL OF PETROLEUM 78-85, *and* N.R. WARPINSKI ET AL. *Mapping hydraulic fracture growth and geometry using microseismic events detected by a wireline retrievable accelerometer array*. Presented at the Society of Petroleum Engineers Gas Technology Symposium, Calgary, Alberta, Canada (1998).
[92] TIEMANN & VANN, *supra* note 87 at 4-5.
[93] *See, e.g.*, Jack Z. Smith, *Two Lawsuits Contend Groundwater in Barnett Shale Contaminated by Drilling*, FORT WORTH STAR-TELEGRAM, December 15, 2010, *available at* http://www.star-telegram.com/2010/12/15/2707805/two-lawsuits-contend-groundwater.html (last visited September 20, 2012).
[94] Memorandum from Richard M. Fetzer to Dennis P. Carney, U.S. EPA, "Action Memorandum – Request for Funding for a Removal Action at the Dimock Residential Groundwater Site" (January 19, 2012), *available at* http://www.epaosc.org/sites/7555/files/dimock-action-memo-01-19-12%5B1%5D.pdf (last visited September 17, 2012).
[95] Press Release, EPA, EPA Completes Drinking Water Sampling in Dimock, Pa. (July 25, 2012), *available at* http://yosemite.epa.gov/opa/admpress.nsf/d0cf6618525a9efb85257359003fb69d/1a6e49d193e1007585257a46005b61ad!opendocument, (last visited September 17, 2012). For more information about the Dimock investigation, visit EPA's website, EPA in Pennsylvania, *available at* http://www.epa.gov/aboutepa/states/pa.html (last visited September 28, 2012).
[96] EPA, *supra* note 95.
[97] EPA, *supra* note 95.
[98] Press Release, EPA, EPA Releases Draft Findings of Pavillion, Wyoming Ground Water Investigation for Public Comment and Independent Scientific Review (December 8, 2011), *available at* http://yosemite.epa.gov/opa/admpress.nsf/20ed1dfa1751192c8525735900400c30/ef35bd26a80d6ce3852579600065c94e!OpenDocument (last visited September 28, 2012). EPA Region 8's summary page for the Pavillion investigation, which includes area background

investigation, EPA detected synthetic chemicals (chemicals not normally occurring in that area's geologic formations) typically used in hydraulic fracturing fluids, as well as benzene and high methane levels.[99] Sampling of shallower drinking water wells detected methane, petroleum hydrocarbons and other chemicals that at least suggest the migration of materials from oil and gas wells, though these chemicals were at levels below health and safety standards.[100]

The coincidence of water well complaints and drilling activities at least suggests some link between the two, but the question remains exactly what mechanism is at work. Some stakeholders worry that hydraulic fracturing caused the contamination observed in Dimock, Pavillion, and other areas hypothesize that the injection of hydraulic fracturing fluid into shale formations dissolves minerals and mobilizes them into the fluid and/or groundwater already in place, with those fluids then flowing through either the induced fractures or existing ones into fresh groundwater formations. Those arguing that hydraulic fracturing could not be the source of such contamination pose a number of alternative explanations. One such explanation is that the materials were already present in the fresh groundwater wells, perhaps in the form of scaling on the wellbore, and are loosened by the energy exerted on the ground by seismic exploration or drilling activities.[101]

Two recent studies conducted by Duke University sought to determine the links, if any, between hydraulic fracturing and the presence of methane in drinking wells and brines in shallow aquifers within the Marcellus shale area. In the methane study, water wells in active areas (defined in the study as having one or more wells within one kilometer of the water well) showed increased methane levels the closer the water well was to a shale-gas well.[102] Chemical analysis of the methane recovered from water well samples suggested the gas came from deeper formations (possibly the shale formation) rather than from biological processes nearer to the surface.[103] At the same time, water samples retrieved during the study indicated that neither Marcellus shale formation water nor hydraulic fracturing fluids were mixing with the well water.[104] The study authors posit three potential explanations for increased methane concentrations in water wells near natural gas wells: (1) the physical displacement of gas-rich liquids from the shale itself into shallower fresh groundwater formations, (2) leaky gas-well casings that allowed methane to pass through fractures into the fresh groundwater formations, and (3) the creation of new fractures or enlargement of existing ones beyond the shale formation, allowing methane to leave the gas-water solution and permeate the geologic layers above. The

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information along with sampling data and the draft report is available at http://www.epa.gov/region8/superfund/wy/pavillion/index.html (last visited September 28, 2012).

[99] *Id.*

[100] *Id.*

[101] CHARLES G. GROAT AND THOMAS W. GRIMSHAW, FACT BASED REGULATION FOR ENVIRONMENTAL PROTECTION IN SHALE GAS DEVELOPMENT, 19 (2012). This study provides a large compilation of scientific literature and regulatory provisions governing the hydraulic fracturing process. However, the study has come under criticism after it was disclosed that at least one of the authors had ties to the oil and gas industry, calling into question the objectivity of the study. *See* Press Release, University of Texas at Austin, Experts to Examine University of Texas Hydraulic Fracturing Study (August 14, 2012), *available at* http://energy.utexas.edu/ (last visited September 27, 2012). The study is currently under review by a panel of experts to examine its objectivity. Given this, the authors of this work have sought to cite the Groat & Grimshaw work only where it contains citations to peer-reviewed literature, statutory or regulatory compilations, or where the report offers ideas for consideration without assigning normative values to those ideas.

[102] Steven G. Osborn, Avner Vengosh, Nathaniel R. Warner, and Robert B. Jackson, *Methane Contamination of Drinking Water Accompanying Gas-Well Drilling and Hydraulic Fracturing*, 108:20 PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES, 8172 (2011), *available at* http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3100993/pdf/pnas.1100682108.pdf (last visited September 27, 2012).

[103] Osborn et al., *supra* note 102 at 8174.

[104] Osborn et al., *supra* note 102 at 8175.

authors noted their findings did not tend to support explanation (1), but did not rule out (2) or (3) as possible pathways.[105] In the brine study, authors found that naturally existing pathways were the most likely explanation for mixing of deep-formation brines with shallower water formations.[106] While noting that it is unlikely that drilling and hydraulic fracturing caused brine to move quickly from deep formations into these shallow aquifers (which, in some cases, may be used for drinking water sources), the authors also noted that the natural pathways suggested by the research could present an additional means by which gas leaking from over-pressurized wells could lead to methane-driven bubble flows that could lift the brine to shallower formations.[107] This creates concerns that the natural pathways could make some areas more vulnerable to brine contaminations triggered, although perhaps indirectly, by hydraulic fracturing and natural gas production.[108]

The Duke studies represent the most recent attempts to explore the potential connections between hydraulic fracturing and groundwater contamination. These studies show that understanding the hydrological and geological forces at work requires intensive study of the area in question. This likely means that understanding the forces at work in a particular region requires studies specific to that region and is not susceptible to "blanket" studies or sweeping generalizations. A number of hypothesized mechanisms for hydraulic fracturing fluid, hydrocarbon, gas, and mineral migration could be at work, but more research is needed to determine if this is mere speculation or fact.[109]

Another difficulty persistently frustrating efforts to conclusively determine if hydraulic fracturing is the cause of water well contamination is a lack of sound baseline water quality data. As stated by Dr. Avner Vengosh, co-author of the Duke studies:

> … the take-home message of this study is that pre-drilling water quality monitoring is important for evaluating water-quality baselines that can be used to detect future changes in water quality, and for evaluating possible hydraulic 'short cuts' and pathways between fluids and gases in deep shale gas formations and shallow aquifers… Such geochemical reconnaissance would provide a better risk assessment for water contamination in newly developed shale gas exploration areas.[110]

The one consensus found in reviewing the scientific literature available on the connection of shale formations with fresh groundwater formation is that much more objective, research-based information on the topic is needed.[111] EPA's hydraulic fracturing study contains elements targeted at understanding these geologic and hydrologic connections,[112]

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[105] *See id.* at 8175.
[106] Nathaniel R. Warner, Robert B. Jackson, Thomas H. Darrah, Steven G. Osborn, Adrian Down, Kaiguang Zhao, Alissa White, and Avner Vengosh, *Geochemical Evidence for Possible Natural Migration of Marcellus Formation Brine to Shallow Aquifers in Pennsylvania*, 109:30 PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES, 11961 (2012), *available at* http://www.pnas.org/content/109/30/11961.full.pdf, (last visited September 17, 2012).
[107] Warner et al, *supra* note 106 at 11965.
[108] *See id.* at 11965.
[109] For a compilation of several of these hypotheses and articles discussing them, *see See, e.g.*, Daniel J. Rozeel and Sheldon J. Reaven, *Water Pollution Risk Associated with Natural Gas Extraction from the Marcellus Shale*, 32:8 RISK ANALYSIS 1382, 1387 (2012).
[110] Press Release, Duke University, "Marcellus Brine Migration Likely Natural, Not Man-Made" (July 9, 2012), *available at* http://today.duke.edu/2012/07/marcellus, last visited September 17, 2012.
[111] *See, e.g.*, TIEMANN & VANN, *supra* note 87 at 19, noting "[h]owever, EPA found that very little documented research had been done on the environmental impacts of injecting fracturing fluids."
[112] *See* EPA, *supra* note 67 at 37.

but as noted above, the study is not slated for completion until 2014. Pennsylvania effectively requires oil and gas operators to document the water quality in the area surrounding a well.[113] Seven other states have some form of baseline testing requirement,[114] and other states have initiated voluntary baseline testing programs.[115] It seems clear that both pre- and post-hydraulic fracturing water quality monitoring will grow in importance, as will the issue of who will pay for it.

3.1.1.3. Concerns Regarding Well Integrity

While many stakeholders worry that hydraulic fracturing will create fractures beyond the intended formation or other pathways through the geologic strata to allow the migration of hydrocarbons or hydraulic fracturing fluids, others worry that the wellbore itself (or other wellbores nearby) will create such pathways. Specifically, the potential for well failure, improperly cemented wells, and abandoned wells that are closed improperly raise concerns about fluid and gas migration.[116]

As an oil or gas well is drilled, operators install successive pieces of casing to form the mechanical structure of the well. Once a string of casing is in place, the operator pumps concrete through the casing and back up along its exterior to create a seal between the casing and the formations it penetrates, as well as sealing the joints between pieces of casing.[117] Proper cementing of the wellbore should create a seal throughout the annulus to prevent interactions between the wellbore and the surrounding formations, both laterally or radially (in a horizontal direction out from the wellbore) and vertically (in a vertical direction along the wellbore). However, improperly cemented wells have been suspected of enabling gas or other materials to infiltrate fresh groundwater formations.[118] Some researchers speculate that a lack of cement along the entire depth of some wells creates pathways along those wells for both water and gases (such as methane) to migrate from their original sources.[119]

Many states with a history of oil and gas development deploy a host of regulations to combat these very concerns. First, to separate these pathways from one another, several states require minimum distances between oil and gas wellbores and water wells to minimize the risk of interaction between the two. Eight states have such "setback requirements" for private water wells,[120] and nine have setbacks for public water supplies.[121] A number of states also have requirements that any well intercepting fresh

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[113] *See* 58 PA. CONS. STAT. § 3218(c) (2012). Colorado has instituted a statewide voluntary baseline testing program, though it is targeting 100% participation by all oil and gas operators in the state. *See* COLORADO OIL AND GAS ASSOCIATION, *infra* note 115.
[114] *See* GROAT & GRIMSHAW, *supra* note 101 at 105.
[115] *See, e.g.* COLORADO OIL AND GAS ASSOCIATION (COGA), COGA BASELINE GROUNDWATER QUALITY SAMPLING PROGRAM, (2012) available at http://www.coga.org/index.php/BaselineWaterSampling/FAQ, last visited September 18, 2012.
[116] *See* GROAT & GRIMSHAW, *supra* note 101 at 18.
[117] DOE, *supra* note 123 at 52.
[118] David M. Karbo, Ron G. Wilhelm, and David J. Campbell, *Natural Gas Plays in the Marcellus Shale: Challenges and Potential Opportunities*, 44 ENVIRONMENTAL SCIENCE AND TECHNOLOGY, 5679, 5682 (2010).
[119] *See, e.g.* P.B. MCMAHON, J.C. THOMAS, AND A.G. HUNT, USE OF DIVERSE GEOCHEMICAL DATA SETS TO DETERMINE SOURCES AND SINKS OF NITRATE AND METHANE IN GROUNDWATER, GARFIELD COUNTY, COLORADO, 2009, 37 (2011), *available at* http://pubs.usgs.gov/sir/2010/5215/ (last visited September 27, 2012).
[120] GROAT & GRIMSHAW, *supra* note 101 at 42. Please note that as of this writing, the report has not been compiled into a final, consecutively-paginated form, and thus page references may be inconsistent. Every effort will be made to correct these references as the publication is finalized.
[121] *Id.* at 43.

groundwater must have some combination of casing and cementing to a depth below the fresh groundwater formation. At least 16 states require some level of these protections, which also include specifications for the casing used, cement strength and cement procedures.[122]

Well failure issues, sometimes also called well integrity issues, arise when the well casing and/or its cement seal become damaged due to the heat or pressures of the underground environment or by the action of the sometimes corrosive materials flowing through the well. One study of failure probability in properly constructed, cased, and cemented Class II injection wells (wells used for the injection of water to produce oil and gas, but not used for hydraulic fracturing operations) conducted by the American Petroleum Institute (API) estimated the odds that injected fluids would reach an underground source of drinking water (USDW) between 1 in 200,000 and 1 in 200,000,000.[123] However, this probability calculation has been criticized in a number of scientific articles.[124] Further, most risk analyses assume properly constructed wells. Well failures can also arise from improper well construction. Most oil and gas producing states impose requirements for well construction and testing to contend with this issue. [125]

While these regulations have required operators to use a number of safeguards against fresh groundwater contamination in wells for several decades, there remains the issue of wells created before these regulations were in place. While current regulations require operators to properly plug wells no longer in use, such requirements have not always existed, meaning numerous wells drilled in the early days of the industry may not be plugged. Such wells could create additional pathways connecting the hydrocarbon-bearing formations to fresh groundwater formations allowing the exchange of constituents between the two. The presence of such abandoned wells could pose problems even in areas where significant geological separations exist between the formations.[126]

Contributing to the issue of abandoned or improperly cased and cemented wells is the number of such wells. A survey conducted in 2000 by the Interstate Oil and Gas Compact Commission (IOGCC) estimated that there were approximately 57,064 "orphaned" wells – wells not actively producing oil or gas, and for which the operator was unknown or insolvent.[127] Beyond these identified wells, numerous undocumented wells may exist. While some states have established well-plugging funds or bonding requirements, these funds have frequently proven insufficient to plug abandoned wells in a timely fashion.[128] The research indicated that the most recent estimate of wells waiting to be plugged with public funds came was dated 2000 and indicated over 42,000 wells in the queue

[122] *Id.* at 56-62.
[123] DOE, *supra* note 39 at 53, *citing* MICHIE & ASSOCIATES, OIL AND GAS WATER INJECTION WELL CORROSION, prepared for the American Petroleum Institute (1988).
[124] *See, e.g.*, Rozeel and Reaven, *supra* note 109 at 1386-1387 (2012).
[125] *See generally* GROAT & GRIMSHAW, *supra* note 101 at 56-64 for a summary of a number of these regulations, including specifications for well construction and cement programs, as well as "logging" of wells to document well integrity.
[126] *See* Osborn et al., *supra* note 102 at 8175.
[127] INTERSTATE OIL AND GAS COMPACT COMMISSION, PRODUCE OR PLUG: A STUDY OF IDLE OIL AND GAS WELLS, 5 (2000). For a summary of the types and amounts of financial assurance states require to ensure the plugging of wells, *see id.* at 28.
[128] *See, e.g.*, RAILROAD COMMISSION OF TEXAS, WELL PLUGGING DIVISION, WELL PLUGGING PRIMER, 1 (2000), *available at* http://www.rrc.state.tx.us/forms/publications/plugprimer1.pdf (last visited September 28, 2012).

nationwide; in all likelihood, this number has grown significantly since then with the rapid expansion of natural gas development.[129]

3.1.1.4. Hydraulic Fracturing Fluid Component Disclosure

The contents of the fluids used in the hydraulic fracturing process receive almost as much discussion as the process itself. As discussed earlier, hydraulic fracturing fluids (sometimes called "frack" or "frac" fluids) contain a number of constituents needed to accomplish a host of tasks in the fracturing process. Generally, water comprises the bulk of the fluid. After water, the "proppant" (most frequently silica or quartz sand) serves as the largest component of the fracturing fluid. The proppant holds the fractures created by the process open, allowing the natural gas to flow into the wellbore. Combined, water and proppant frequently serve as 98 percent to 99.5 percent of the total fluid volume, and all the other constituents of the fluid comprising the remaining 0.5 percent to 2 percent.[130] Developers carefully design the fracturing program to the specific formations at each well; this means that fracturing fluid mixes may vary from well to well.[131] Oilfield service companies supplying fracturing fluids invest significant research in developing improved fluid designs and will sometimes claim the formula of their mixes are "proprietary" and cannot be disclosed.

Though much of the discussion of the chemical components of fracturing fluid focuses on the relative proportions of those chemicals, the toxicity of those chemicals in the environment may bear little or no correlation to their proportion of the fluid mix. Take for an example a biocide[132] component of a fracturing fluid, which may comprise 0.001% of the fluid.[133] In a multi-stage fracturing operation using 2 million gallons of fluid,[134] this equates to 20 gallons of the biocide at an initial concentration 10 ppm – a concentration below the levels found to cause toxicity effects in laboratory trials.[135] Interaction with subsurface water and other substances could further dilute the biocide. However, other factors could influence the fluid and cause increased concentrations depending on the hydrology and chemistry at play in the formation. Much more research is needed to determine the dilution and fate of these constituents in the hydraulic fracturing and shale environment before definitive statements can be made about the impacts of fracturing fluid components in the environment.

As discussed above, many stakeholders express concern that hydraulic fracturing fluids may leave the targeted formations and find their way into fresh groundwater supplies. Those concerns include not only the migration of hydrocarbons, metals, and other minerals already found in those underground formations, but also the introduction of new chemical

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[129] *See, e.g.* COLORADO OIL AND GAS ASSOCIATION (COGA), COGA BASELINE GROUNDWATER QUALITY SAMPLING PROGRAM, (2012) available at http://www.coga.org/index.php/BaselineWaterSampling/FAQ, last visited September 18, 2012. [129] INTERSTATE OIL AND GAS COMPACT COMMISSION, PRODUCE OR PLUG: A STUDY OF IDLE OIL AND GAS WELLS, 1 (2000).
[130] DOE, *supra* note 123 at 61.
[131] *Id.* at 62.
[132] An example of a material used as a biocide in fracturing fluid is Glutaraldehyde. *See* DOE, note 123 at 63.
[133] An example of one fracturing fluid's components on a volumetric basis can be found in DOE, *supra* note 39 at 62.
[134] *See id.* at 58.
[135] *See* EPA, Registration Eligibility Decision for Glutaraldehyde (2007), 9, *available at* http://www.epa.gov/oppsrrd1/REDs/glutaraldehyde-red.pdf (last visited September 28, 2012), noting "No Observed Adverse Effect Levels" (NOAELs) of 500ppm and 50ppm in animal trials for chronic toxicity.

constituents into the underground environment through the injection of hydraulic fracturing fluids.

The sheer number of different chemicals used in hydraulic fracturing fluids may drive at least part of the public's concerns in this area. Operators carefully design the fracturing program to the specific formations at each well; this means that fracturing fluid mixes may vary from well to well.[136] Oilfield service companies supplying fracturing fluids invest significant research in developing improved fluid designs and will sometimes claim the formula of their mixes are "proprietary" and cannot be disclosed. In preparing its plan to study hydraulic fracturing issues, EPA reviewed the publicly-available information on the chemicals used in hydraulic fracturing and found nearly 1,100 different substances.[137] The public may not be familiar with many of these substances, may be intimidated by their complex-looking names, or may see chemicals that have received attention for their hazardous traits. A lack of knowledge about the chemicals used in hydraulic fracturing fluids and their respective proportions of the fluid's volume underscore these concerns and makes development and implementation of regulations governing them more difficult. Further adding to these issues is the secrecy around some fluid formulations claimed as proprietary exacerbated these concerns in some situations.

To facilitate the discussion about hydraulic fracturing, a growing number of jurisdictions now require oil and gas operators to publicly disclose the content of their hydraulic fracturing fluids. A 2012 review of these regulations by the University of Texas Energy Institute found that thirteen states required some form or reporting or disclosure of the materials used in hydraulic fracturing fluids.[138]

Public disclosure of fracturing fluid information gained further attention with the launching of the FracFocus website.[139] FracFocus is a joint project of two other organizations: the Ground Water Protection Council and the Interstate Oil and Gas Compact Commission.[140] Initially, FracFocus served as a voluntary registry where oil and gas operators could list the location of wells and the composition of the hydraulic fracturing fluids used in that well, and the website still serves that function. However, a growing number of states that require disclosure of fracturing fluid composition use the FracFocus website as the clearinghouse for that information and require posting of disclosed information to the site.[141] As of this writing, participants registered nearly 28,000 wells with the site.[142] Determining the proportion of registered wells is difficult as data on the number of active hydraulically fractured wells is scattered; based on industry estimates, a total of over 1 million wells have been hydraulically fractured since the invention of the process.[143]

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[136] *Id.* at 62.
[137] EPA, *supra* note 68 at 119-143
[138] GROAT & GRIMSHAW, *supra* note 101 at 90-93.
[139] The website URL is www.fracfocus.org.
[140] FRACFOCUS, ABOUT US (2012), *available at* http://fracfocus.org/welcome (last visited September 19, 2012).
[141] *See, e.g.* OKLA. ADMIN. CODE § 165:10-3-10, requiring disclosure of information through the FracFocus website and requiring the Oklahoma Corporation Commission to post information it receives to the website.
[142] FRACFOCUS, *supra* note 140.
[143] API, OIL AND NATURAL GAS OVERVIEW: HYDRAULIC FRACTURING Q & A'S, http://www.api.org/oil-and-natural-gas-overview/exploration-and-production/hydraulic-fracturing/hydraulic-fracturing-qa.aspx (last visited September 28, 2012).

Calls for increased disclosure of hydraulic fracturing fluid contents continue. The FRAC Act, discussed above, would require disclosure of fracturing fluid chemicals and volumes that would be disclosed via the web (presumably through FracFocus).[144] The Bureau of Land Management (BLM) has proposed an agency policy that would require the public disclosure of all chemicals used in the hydraulic fracturing of any wells on lands under BLM authority.[145] Conversely, the Fracturing Regulations are Effective in State Hands Act (FRESH Act),[146] would give states authority over hydraulic fracturing taking place on federal lands within the state's borders. Both the FRAC Act and the FRESH Act remain in committee as of this writing.[147]

The Congressional Research Service has compiled a significant amount of information on this topic in its report, "Hydraulic Fracturing: Chemical Disclosure Requirements."[148]

3.1.1.4. Documenting connections between subsurface hydraulic fracturing operations and impacts to fresh groundwater

Any discussion of subsurface hydraulic fracturing operations as mechanisms for moving hydrocarbons, gases, or fluids between extraction zones and fresh groundwater formations must note the hypothetical nature of the discussion. It should be noted here that a search of the available scientific literature has not revealed any studies definitively linking migration of hydraulic fracturing fluids, hydrocarbons, or gases into fresh groundwater formations through wellbores.[149] Although the Duke University studies and the Dimock and Pavillion EPA investigations suggest such a link, each of those studies also noted that the exact mechanism of migration is unknown. If there is any consensus on these issues, it would appear to be that much more research is needed.

3.1.3. Surface Water Issues

Although concerns about groundwater quality receive the bulk of discussion in the hydraulic fracturing debate, many stakeholders also express concern over potential impacts to surface waters. These concerns fall primarily into two categories: (1) the potential for the release of materials from drilling sites to nearby surface waters, and (2) the discharge of fluids from drilling operations to surface waters, either through on-site treatment or by sending those fluids to nearby Publicly Owned Treatment Works (POTWs).

3.1.3.1. Potential Releases from Drilling Sites

Noting the geologic separations frequently found between hydrocarbon formations and fresh groundwater aquifers, some stakeholders regard the operations at the surface of

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[144] TIEMANN & VANN, *supra* note 74 at 22, *citing* H.R. 1084 at § 2(b).
[145] 77 Fed. Reg. 27691-27711 (May 11, 2012).
[146] S. 2248, HR. 4322.
[147] The last major action on H.R. 1084 was its referral to the House Subcommittee on Environment and the Economy on March 21, 2011. The FRESH Act was referred to the Senate Committee on Energy and Natural Resources on March 28, 2012. Bill statuses were checked via the THOMAS system, available at http://thomas.loc.gov/cgi-bin/thomas, last visited September 20, 2012.
[148] BRANDON J. MURRILL AND ADAM VANN, CONG. RES. SERV. R42461, HYDRAULIC FRACTURING: CHEMICAL DISCLOSURE REQUIREMENTS (2012), *available at* http://www.fas.org/sgp/crs/misc/R42461.pdf, last visited September 20, 2012.
[149] A similar conclusion was reached by the Congressional Research Service in their report on hydraulic fracturing and the Safe Drinking Water Act. *See* TIEMANN & VANN, *supra* note 87 at 4.

hydraulic fracturing wells as posing a much greater threat to water quality than the subsurface operations.[150]

As with many industrial activities, hydraulic fracturing can involve the storage of large quantities of chemicals on-site in an undiluted form. While they may pose much less risk of harm as mixed in their final formulation within the fracturing fluid, they can be hazardous in this undiluted form and pose dangers if spilled.[151] To address such concerns, the Clean Water Act[152] (CWA) includes provisions for regulating the discharge of runoff from industrial sites or sites under construction where the disturbance of the area could contribute to the runoff of pollutants. The National Pollutant Discharge Elimination System (NPDES),[153] created by the CWA, regulates the discharge of storm water that may carry pollutants from a site to surface waters. However, the EPAct specifically exempted storm water discharges related to "oil and gas exploration and production" activities from such regulation.[154] As a result, oil and gas wellsites are not required to have a storm water discharge permit under most circumstances.[155] While this exemption precludes the regulation of storm water runoff from wellsites, it does not preclude the regulation of such runoff if the runoff comes into contact with industrial materials and other pollutants from the site.[156] These national exemptions generally leave the management of pollutant runoff from wellsites to the states. Several states impose requirements for the management of storm water, sediment, and erosion from wellsites, usually in the form of a "general permit"[157] or the prescription of "best management practices" for wellsites.

While these provisions deal with runoff from wellsites, the storage of produced water and flowback water represent another area of concern. Operators may store such water in tanks on site, or may use open pits (frequently lined with compacted clay or with synthetic liner materials) to hold the water while it awaits disposal. Some stakeholders express concern for the open-pit storage method, as erosion of the pits' embankments could lead to a loss of containment or excessive rainfall could raise the liquid level in the pit to the point that it overflows the embankment. States that regulate these pits frequently address these concerns with construction standards for such pits and may also impose requirements for the amount of "freeboard" (the height gap between the fluid level and the top elevation of

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150 *See, e.g.* GROAT & GRIMSHAW, *supra* note 101 at 18.

151 GROAT & GRIMSHAW, *supra* note 101 at 30.

152 33 U.S.C. §§ 1251 – 1387.

153 33 U.S.C. §

154 Section 402(*l*)(2) of the Clean Water Act (33 U.S.C. § 1342(*l*)(2) states:

> The Administrator shall not require a permit under this section, nor shall the Administrator directly or indirectly require any State to require a permit, for discharges of stormwater runoff from mining operations or oil and gas exploration, production, processing, or treatment operations or transmission facilities, composed entirely of flows which are from conveyances or systems of conveyances (including but not limited to pipes, conduits, ditches, and channels) used for collecting and conveying precipitation runoff and which are not contaminated by contact with, or do not come into contact with, any overburden, raw material, intermediate products, finished product, byproduct, or waste products located on the site of such operations.

The definition of "oil and gas exploration and production" is found at 33 U.S.C. § 1362(24):

> The term "oil and gas exploration, production, processing, or treatment operations or transmission facilities" means all field activities or operations associated with exploration, production, processing, or treatment operations, or transmission facilities, including activities necessary to prepare a site for drilling and for the movement and placement of drilling equipment, whether or not such field activities or operations may be considered to be construction activities.

155 *See* 40 C.F.R. § 122.26(c)(1)(iii); *see also* EPA, REGULATION OF OIL AND GAS CONSTRUCTION ACTIVITIES, available at http://cfpub.epa.gov/npdes/stormwater/oilgas.cfm, last visited September 20, 2012.

156 *See* 33 U.S.C. § 1342(*l*)(2).

157 A "general permit" contains set requirements that apply to all permit holders; in comparison, an "individual permit" contains conditions tailored specifically to the individual permit holder."

the embankment) that must be maintained.[158] Other jurisdictions look to containment requirements that further reduce the risk of accidental discharge to surface waters. New York, for example, has considered requiring water to be stored in tanks rather than pits to minimize discharge risks.[159]

3.1.3.2. Point-source Discharges of Treated Water and POTW Issues

In most cases, operators dispose of flowback and produced water via underground injection.[160] Constraints in some areas render this method of disposal impractical, which may compel the operator to treat and discharge the water or to truck it to a disposal facility. If the operator chooses to treat and discharge the water from their own facility, an NPDES permit for the discharge must be obtained from EPA or the state agency acting under EPA's delegated authority.[161]

In some areas, particularly those near population centers, the operator may have the option of transferring the water via pipeline to a publicly-owned treatment works (POTW), typically operated by a municipal or regional entity. The water is transferred to the POTW to remove pollutants so that it may be discharged safely to surface waters. Successful use of this disposal method requires compatibility between the water and the POTW's treatment processes. Some waters produced by the hydraulic fracturing process may contain chemical constituents that interfere with the POTW's biological treatment processes or simply pass through and can cause the POTW to violate its discharge restrictions.[162] In such cases, the operator must pre-treat the water to a level compatible with the POTW's processes, and may require an industrial pre-treatment permit under the NPDES or delegated state program.[163] Alternatively, the operator may have to truck the water to a disposal site capable of handling the wastewater; this can significantly increase truck traffic in the area and add pressure to public infrastructure as discussed below.

3.2. Water Quantity Issues

While some stakeholders' primary concern rests in the quality of the water available, others focus on the quantity. While some areas of the country have dealt with water allocation issues for several years, others are just now facing issues of water scarcity. In some areas, the recent drought has highlighted water allocation issues, pitting agricultural uses directly against withdrawals for oil and gas production.[164]

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[158] For a collection of state regulations applicable to storage pits, *see* GROAT & GRIMSHAW, *supra* note 101 at 109-112.

[159] *See* EPA, *supra* note 67 at 43, *citing* NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION (NYSDEC), SUPPLEMENTAL GENERIC ENVIRONMENTAL IMPACT STATEMENT ON THE OIL, GAS AND SOLUTION MINING REGULATORY PROGRAM (REVISED DRAFT), WELL PERMIT ISSUANCE FOR HORIZONTAL DRILLING AND HIGH-VOLUME HYDRAULIC FRACTURING TO DEVELOP THE MARCELLUS SHALE AND OTHER LOW-PERMEABILITY GAS RESERVOIRS (2012), *available at* http://www.dec.ny.gov/energy/75370.html (last visited September 27, 2012).

[160] *See* EPA, *supra* note 67 at 48, *citing* Veil, J. A. (2010, July). *Final report: Water management technologies used by Marcellus Shale gas producers.* Prepared for the US Department of Energy, National Energy Technology Laboratory, Department of Energy award no. FWP 49462. Argonne, IL: Argonne National Laboratory. Retrieved on January 20, 2011, from http://www.evs.anl.gov/pub/doc/Water%20Mgmt%20in%20Marcellus-final-jul10.pdf.

[161] Such discharges do not fall under any of the exemptions to the discharge permitting requirements discussed in 33 U.S.C. § 1342.

[162] *See* EPA, *supra* note 67 at 48, *citing* J.A. Veil, FINAL REPORT: WATER MANAGEMENT TECHNOLOGIES USED BY MARCELLUS SHALE GAS PRODUCERS. (2010), *available at* http://www.evs.anl.gov/pub/dsp_detail.cfm?pubID=2537 (last visited September 27, 2012).

[163] *See generally* 40 C.F.R. Part 403.

[164] *See, e.g.* Blake Ellis, *Oil Companies Desperately Seek Water Amid Kansas Drought*, CNN MONEY (August 10, 2012), *available at* http://money.cnn.com/2012/08/10/news/economy/kansas-oil-boom-drought/index.html?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed:+rss/money_latest+(Latest+News), last visited September 20, 2012.

Two issues emerge in the discussion of the amount of water used for hydraulic fracturing: the amount of water needed, and the source of the water.

3.2.1. Quantities of Water Needed for Hydraulic Fracturing Processes

As noted above, water comprises the vast majority of hydraulic fracturing fluid. Beyond its functions in suspending and transmitting the other fluid components, the volume of the water itself serves a role in filling the wellbore (which can be substantial in horizontal drilling programs) and serving as a virtually incompressible fluid to exert force against the hydrocarbon formation. Water may be lost to the formation as the fracturing process proceeds, although a portion of this water may return to the surface as flowback water.

As with so many other aspects of hydraulic fracturing operations, the amount of water used varies on a well-by-well basis. The following table shows one estimate of the per-well amounts of water used for wells in a number of shale formations.

Table 3-3. Examples of Water Use per Well in Various Shale Plays[165]

Shale Play	Formation Depth (ft)	Porosity (%)	Organic Content (%)	Freshwater Depth (ft)	Fracturing Water (gallons/well)
Barnett	6,500-8,500	4-5	4.5	1,200	2,300,000
Fayetteville	1,000-7,000	2-8	4-10	500	2,900,000
Haynesville	10,500-13,500	8-9	0.5-4	400	2,700,000
Marcellus	4,000-8,500	10	3-12	850	3,800,000

A lack of data confounds the discussion of hydraulic fracturing's water use. Many different estimates of both individual water use and aggregate consumption by the industry exist. For example, the table above comes from the "EPA Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resource," and indicates the typical well in the Marcellus Shale uses approximately 3.8 million gallons. However, in testimony before the U.S. Senate, the deputy director of the Susquehanna River Basin Commission (SRBC) reported that the average per well water use as 4.24 million gallons.[166] One study estimates the average water amount of water used to hydraulically fracture an Eagle Ford Shale well at 6.1 million gallons[167], while another estimates 13 million gallons.[168] At least part of this issue appears to stem from inconsistent requirements for monitoring and reporting water use. For example, some water agencies require flow monitors on water withdrawal points while others rely on self-reporting of water use by the user.[169] Changing the water monitoring requirements across a number of jurisdictions again raises the question of which groups will pay for such monitoring. Another barrier to effective

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[165] Table source: Source: EPA, *supra* note 32 at 22 (2011), *citing* data from Groundwater Protection Council and ALL Consulting, 2009

[166] *Hearing on Shale Gas Production and Water Resources in the Eastern United States Before the Senate Committee on Energy and Natural Resources,* 112th Cong. (2011) (statement of Thomas W. Beauduy, Deputy Executive Director and Counsel for the Susquehanna River Basin Commission, at 8), *available at* http://www.energy.senate.gov/public/index.cfm/files/serve?File_id=0da002e7-87d9-41a1-8e4f-5ab8dd42d7cf (last visited September 21, 2012).

[167] GROAT & GRIMSHAW, *supra* note 101 at 24.

[168] HEATHER COOLEY AND KRISTINA DONNELLY, HYDRAULIC FRACTURING AND WATER RESOURCES: SEPARATING THE FRACK FROM THE FICTION at 15 (2012), *citing* J.P. NICOT ET AL., CURRENT AND PROJECTED WATER USE IN THE TEXAS MINING AND OIL AND GAS INDUSTRY. (2011).

[169] A number of Colorado's water basins require flow meters for wells and submission of meter readings. *See, e.g.* 2 COLO. CODE REGS. §§ 402-16.5 and 402-16.8 (2012). Conversely, Oklahoma's regulations for "provisional temporary permits" (the water use permit most frequently used for oil and natural gas wells" contain no requirements for monitoring or reporting. *See* OKLA. ADMIN. CODE § 785:30-5-4 (2012).

information is the "patchwork of agencies responsible for various water sources"[170] that can lead to differing regulation systems even within the same state.

Even in the face of inconsistency in the data, there appears some consensus that the use of water for hydraulic fracturing represents a significant new water use. Using what some may regard as conservative numbers (though others may regard it as less conservative), EPA estimated the annual water use for hydraulically fractured wells aggregated to a range between 70 and 140 billion gallons, a range that would equate to the water use of one to two cities of 2.5 million people each.[171] Using the 140 billion gallon estimate, and comparing it to the estimated annual water use of the U.S. – 410,000 million gallons per day, or 149 trillion gallons per year[172] - this represents only 0.09 percent of total water use. However, that small number may be misleading, as discussed in the next subsection.

3.2.2. Water Sources

Scientists and water users would quickly respond to the statistic above to by saying aggregate water use poses little relevance; the specific water uses within a hydrological system such as a watershed or aquifer are much more important than the aggregate water use over the nation. Thus, the most relevant area of focus for discussion of water use may be within a specific water supply.

Determining the true impact of any water use on a surface water or aquifer depends, at least in part, on how much of the water returns to that source after use. Water uses that result in a large proportion of the withdrawal leaving the source without a return are called "consumptive" uses.[173] One can think of a recreational stream as a perfectly non-consumptive use; when used only for boating, swimming, or fishing, no water is taken from the system. Conversely, a bottled-water plant represents a perfectly consumptive use – the water is withdrawn from the stream, never to return. Of course, most uses fall somewhere in between the extremes of this continuum. For example, a coal-, gas- or nuclear-fueled power plant may withdraw water for steam and cooling purposes; some of this water is lost to evaporation, but some is returned to the stream. At least one question regarding water use for hydraulic fracturing then becomes whether such use is primarily consumptive or non-consumptive when viewed at the watershed scale.

Again, since wells are unique, categorical answers do not present themselves. Resolving the question depends at least in part on how much of the water used in the hydraulic fracturing process returns to the surface. The amount of this returning water, called "flowback"[174] water, varies from well to well and formation to formation. At least one study has estimated that anywhere from 20 to 80 percent of injected water remains in the

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[170] GROAT & GRIMSHAW, *supra* note 101 at 25.
[171] EPA, *supra* note 68 at 22.
[172] NANCY L. BARBER, U.S. GEOLOGICAL SURVEY (USGS) FACT SHEET 2009-3098, SUMMARY OF ESTIMATED WATER USE IN THE UNITED STATES IN 2005, (2009), *available at* http://pubs.gov/fs/2009/3098/pdf/2009-3098.pdf (last visited September 21, 2012).
[173] *See* JASPER WOMACH, CONG. RESEARCH SERV., AGRICULTURE: A GLOSSARY OF TERMS, PROGRAMS, AND LAWS, 2005 EDITION, 59, *available at* http://www.cnie.org/NLE/CRSreports/05jun/97-905.pdf (last visited September 21, 2012).
[174] As noted in Section 2, there can be confusion in the distinction between "flowback" and "produced" water. For the purposes of this discussion, "flowback" is used to describe water injected into the wellbore that returns to the surface, and "produced" water is used to describe water that was already present in the hydrocarbon-bearing formation that is forced to the surface by the natural gas extraction process.

subsurface, meaning that anywhere from 80 to 20 percent of the water may be recovered as flowback.[175] One report from the Marcellus Shale estimates average recovery of flowback as percentage of total injected water to range from 5 to 12 percent.[176] Flowback water is only one component of the water produced from a hydraulically fractured well. Produced water from the hydrocarbon formation may also return to the surface. In some formations such as the Barnett, the volume of produced water far exceeds the volumes of water injected, while in others such as the Marcellus, it is only a fraction of the injected volume.

Table 3-4. Flowback Water Volume Characteristics[177]

	Frac Water Volume (Mgal)	Flowback @ 10 Days (Mgal)	Ultimate Produced Water (Mgal)	Recovery Ratio
Barnett	3.8	0.6	11.730	3.1
Haynesville	5.5	0.25	4.475	0.9
Fayetteville	4.2	0.5	0.980	0.25
Marcellus	5.5	0.5	0.700	0.15

The amount of flowback and produced water alone cannot define whether the hydraulic fracturing operation represents a consumptive use. The answer to that question rests on the characteristics of the flowback and produced water. If such waters can be treated and returned to the source from which they were withdrawn, the consumptive impact of the well may be negligible. Alternatively, if such waters cannot be treated and returned, the well must be regarded as a consumptive use and the water it uses must also be regarded as removed from the water cycle.

The treatability of these waters depends largely on their chemical traits. In the case of flowback water, treatment will undoubtedly involve removal of many components added to the water to form the fracturing fluid. With produced water, the level of dissolved minerals frequently represents the limiting factor in whether it can be treated and discharged or alternatively disposed. Produced water from hydraulically fractured wells may range from freshwater quality (less than 5,000 parts per million [ppm] of total dissolved solids [TDS]) to hyper-saturated brines (greater than 400,000 ppm TDS).[178]

Waters with relatively low dissolved solids (TDS) may be easier to treat and reuse or treat and discharge, potentially returning water to the hydrologic system from which it came. Higher TDS levels may make it difficult for operators to reuse the water for subsequent hydraulic fracturing operations, as the minerals in the water can disrupt the needed chemical traits of the fracturing fluid.[179] High TDS levels also make treatment of the water more difficult.[180] On the other hand, continuous improvements in technology enable operators to use an increasing amount of flowback and produced water again as recycled

[175] GROAT & GRIMSHAW, *supra* note 101 at 21.
[176] Beauduy, *supra* note 166 at 9.
[177] Table source: GROAT & GRIMSHAW, *supra* note 101 at 22.
[178] DOE, *supra* note 89 at 67-68, *citing* Satterfield, J., M. Mantell, D. Kathol, F. Hiebert, K. Patterson, and R. Lee, *Managing Water Resources Challenges in Select Natural Gas Shale Plays*, presented at the GWPC Annual Meeting. September 2008.
[179] EPA, *supra* note 68 at 23, *citing* J. Bryant, T. Welton, J. Haggstrom, *Will Flowback or Produced Water Do?* E&P Magazine (September 1, 2010), *available at* http://www.epmag.com/Magazine/2010/9/item65818.php (last visited September 27, 2012).
[180] For a discussion of how high pollutant levels can disrupt treatment systems such as POTWs, *see* section 3.1.3.2 above.

fracturing fluid; pilot studies indicate the potential to treat such water to levels that make it suitable for irrigation or drinking water.[181]

The increasing ability of operators to reduce the consumptive impact of water withdrawals for hydraulic fracturing through reuse and recycling of flowback and produced water helps to alleviate some water use concerns, but others still remain. Water use for hydraulic fracturing usually means an "acute" withdrawal of water, meaning that significant volumes of water are needed in a short time span. This nature of withdrawals can have significant impacts on a hydrological system depending on the time and location of the withdrawal. As stated by one officer of the SRBC, "[q]uantities of water that one could otherwise consider inconsequential on a major tributary can represent an important component of the flow regime in headwater areas."[182] Large volume withdrawals from streams can trigger significant changes to the flow depth, velocity, and temperature of the streams[183] while also affecting the concentration of contaminants. Significant volume changes can have direct impacts on other uses such as irrigation and hydroelectric generation depending on when such withdrawals are made. Further, withdrawals from surface water sources can impact groundwater sources, and vice versa,[184] a fact that has not been addressed in many states' water allocation systems.

Withdrawals from groundwater also pose potential unintended consequences to water availability and chemistry by lowering the water level in those formations. This can have the effect of requiring deeper wells for other water users.[185] Further, lowering water levels in these aquifers can have a number of impacts:

> Withdrawals of large volumes of ground water can lower the water levels in aquifers. This can affect the aquifer water quality by exposing naturally occurring minerals to an oxygen-rich environment, potentially causing chemical changes that affect mineral solubility and mobility, leading to salination of the water and other chemical contaminations. Additionally, lowered water tables may stimulate bacterial growth, causing taste and odor problems. Depletion of aquifers can also cause an upwelling of lower quality water and other substances (e.g., methane from shallow deposits) from deeper within an aquifer and could lead to subsidence and/or destabilization of the geology.[186]

The potential water quality triggers actuated by reduced water levels show that while water quality and quantity issues may seem separate, they are in many ways linked. Given all these considerations, any discussion about policy alternatives for handling water

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181 *See* DOE, *supra* note 89 at 70.
182 Beauduy, *supra* note 166 at 4.
183 EPA, *supra* note 68 at 27, *citing* T.G. ZORN ET AL., STATE OF MICHIGAN DEPARTMENT OF NATURAL RESOURCES REPORT 2089, A REGIONAL-SCALE HABITAT SUITABILITY MODEL TO ASSESS THE EFFECTS OF FLOW REDUCTION ON FISH ASSEMBLAGES IN MICHIGAN STREAMS, (2010), *available at* http://www.michigandnr.com/PUBLICATIONS/PDFS/ifr/ifrlibra/Research/reports/2089/RR2089.pdf (last visited September 27, 2012), and PENNSYLVANIA STATE UNIVERSITY, MARCELLUS EDUCATION FACT SHEET: WATER WITHDRAWALS FOR DEVELOPMENT OF MARCELLUS SHALE GAS IN PENNSYLVANIA: INTRODUCTION TO PENNSYLVANIA'S WATER RESOURCES (2010), *available at* http://pubs.cas.psu.edu/freepubs/pdfs/ua460.pdf (last visited September 27, 2012).
184 T. C Winter, et al., U.S. Geological Survey Circular 1139, Ground Water and Surface Water: A Single Resource, 1-78 (1998), *available at* http://pubs.usgs.gov/circ/circ1139/#pdf (last visited September 27, 2012).
185 EPA, *supra* note 68 at 25, *citing* Louisiana Office of Conservation Order No. ENV 2011-GW014 (August 19, 2011), *available at* http://dnr.louisiana.gov/assets/news_releases/OrderENV2011-GW0140001.pdf (last visited September 27, 2012).
186 EPA, *supra* note 68 at 27.

withdrawals for hydraulic fracturing necessarily turns on very specific regional issues such as hydrology, water chemistry, aquatic biology, geology, and competing water uses.

3.3. Air Quality Issues

An oil or natural gas well naturally has some pollutant emission sources, regardless of whether it employs hydraulic fracturing processes. In the exploration phase, a rig at the wellsite must use large engines (often called "prime movers") that are used to power the rest of the mechanical and electrical equipment on the drilling rig.[187] A list of some common pollutant sources from the exploration phase and their emissions follows. It should be noted that the exact contributions of each activity to the total pollutant mix from a wellsite is difficult to determine due to the fugitive nature of many sources.[188]

Table 3-5. Common Air Pollutants and Sources from Oil and Gas Exploration Rigs[189]

Onshore Exploration Source Type	Specific Emission Sources	Potential Pollutants[a]
Drilling Rigs	Diesel engines to run electricity generators	SO_2, NO_x, VOC, PM_{10}, $PM_{2.5}$, CO
	Drill mud degassing (open pits or storage tanks)	VOC
Gas Well Completion	Emissions from flaring from the gas well completion phase	CO, NO_X, VOC
	Emissions from venting from the gas well completion phase	VOC
Oil Well Completion	Emissions from flaring from the oil well completion phase	CO, NO_X, VOC, SO_2
	Emissions from venting from the oil well completion phase	VOC
Gas Well Pneumatic Devices	Fugitive emissions from pneumatic devices used during gas well exploration and production	VOC
Oil Well Pneumatic Devices	Fugitive emissions from pneumatic devices used during oil well exploration and production	VOC

Once a well is drilled, some gas may return through the wellbore before the connection of the well to a pipeline. Operators may vent this gas to the atmosphere without further treatment. Alternatively, they may "flare" it by igniting it; the flaring process can eliminate a number of atmospheric pollutants and aids in safety by eliminating volatile gas from the area but still results in the emission of carbon dioxide and other materials.[190]

Assuming the rig successfully completes the well and discovers oil or natural gas, the operator will emplace a set of production equipment at the wellsite that may process the oil or gas to remove impurities before it is put into the transmission system. This equipment may include compressors to pressurize gas to the level needed for pipeline transport, "dehydrators" that use a glycol solution to extract water vapor from the gas, a

[187] Norman J. Hyne, Nontechnical Guide to Petroleum Geology, Exploration, Drilling, and Production, 247 (PennWell, 2001).
[188] Lisa M. McKenzie, Roxana Z. Witter, Lee S. Newman, and John Adgate, "Human Health Risk Assessment of Air Emissions from Development of Unconventional Natural Gas Resources," Science of the Total Environment, 424 (2012) 79-87, 80.
[189] Table source: EASTERN RESEARCH GROUP, REPORT FOR TEXAS COMMISSION ON ENVIRONMENTAL QUALITY, EMISSIONS FROM OIL AND GAS PRODUCTION FACILITIES: FINAL REPORT, (2007), 15. Note (a): Abbreviations are as follows: SO_2 – sulfur dioxide, NO_x – nitrogen oxides, VOC – volatile organic compounds, PM_{10} – particulate matter with aerodynamic diameter of 10 microns, $PM_{2.5}$ – particulate matter with aerodynamic diameter of 2.5 microns, CO – carbon monoxide.
[190] RAYMOND &LEFFLER, *supra* note 15 at 137.

"heater-treater" to break up emulsified petroleum liquids, and "sweetening units" to remove hydrogen sulfide from natural gas.[191] In addition to this equipment, piping and tanks are used to store produced petroleum substances until their shipment. A list of some production equipment and its associated emissions is below.

Table 3-6. Common Pollutants and Sources from Oil and Gas Production Equipment[192]

Onshore Production Source Type	Specific Emission Sources	Potential Pollutants[a]
Oil and Gas Well Wellheads	Emissions from wellhead assemblies and rod pumps	VOC
Compressor Engines	Combustion emissions from compressor engines associated with oil and gas production	SO_2, NO_x, VOC, PM_{10}, $PM_{2.5}$, CO
Dehydrators/Separators	Emissions from glycol dehydrator reboilers	VOC
Heater Treaters	Emissions from natural gas-fired heater treaters	NO_x, CO
Oil and Condensate Storage Tanks	Working, breathing, and flashing losses from oil and condensate storage tanks	VOC
Loading of Oil and Condensate	Fugitive emissions from truck and/or railcar loading	VOC
Pump and Piping Component Fugitive Losses	Fugitive emissions from pumps and piping components	VOC
Coal Bed Methane Pump Engines	Natural gas engine emissions used to de-water coal beds	SO_2, NO_x, VOC, PM_{10}, $PM_{2.5}$, CO

Concentrations of these gases and particles can vary widely. Although acute impacts at wellsites from these from these substances are relatively rare, they can be hazardous if present at highly concentrated levels, with impacts to the neural and respiratory systems.[193] Chronic, long-term exposure to some hydrocarbon gases has been linked to increased risks of cancer.[194] Since a great deal of natural gas production occurs in rural areas, it should be noted that atmospheric emissions may impact livestock as well. At least one study has suggested increased risk of reproductive impacts in cattle near gas production and processing facilities that flared sour gas (that is, gas with elevated levels of sulfur).[195]

Increasing the intensity of oil and gas exploration, whether with conventionally-produced vertical wells or hydraulically fractured horizontal wells, in any area will naturally increase these emissions if those emissions are not managed. While outgassing from drilling mud occurs even with conventional oil and gas wells, the greater fluid returned with a hydraulically fractured well through the flowback and produced water serves as an additional emissions source. A number of hydrocarbons and other gases may be entrained in these fluids, which are then released when the fluids are stored in pits or tanks that can vent to the atmosphere.[196] Risk assessment studies on air emissions near hydraulically

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[191] HYNE, *supra* note 187 at 366-369.
[192] Table source: EASTERN RESEARCH GROUP, *supra* note 189 at 15.
[193] *See* Lisa M. McKenzie, et al., *Human Health Risk Assessment of Air Emissions from Development of Unconventional Natural Gas Resources*," 424 SCIENCE OF THE TOTAL ENVIRONMENT 79, 80 (2012).
[194] *Id.*
[195] *See generally* C.L. Waldner, et al., *Associations Between Oil- and Gas-Well Sites, Processing Facilities, Flaring, and Beef Cattle Reproduction and Calf Mortality in Western Canada*, 50 PREVENTATIVE VETERINARY MEDICINE 1 (2001).
[196] *See* McKenzie et al, *supra* note 193 at 80.

fractured wells suggest a statistically significant increase in health impacts from air emissions for persons living closer than one-half mile to such sites. [197]

The U.S. EPA recently enacted rules aimed at curbing emissions from the hydraulic fracturing process. In essence, the new regulations require "green completions" for many gas wells. "Green completion" refers to procedures used to capture and control gas emissions from the very beginning of gas production, including the capture of gases from flowback and produced water.[198] In establishing the New Source Performance Standards (NSPS) for gas wells, EPA required operators to use emissions control measures such as flares until they can implement the green completion technologies proscribed in the NSPS; however, all natural gas wells within the scope of the NSPS must implement green completions no later than January 1, 2015. [199]

A discussion of the air emissions impacts of natural gas would be incomplete without discussing what many regard as an important benefit of natural gas. Many stakeholders view natural gas as vital to reducing greenhouse gas emissions and slowing climate change, serving as a "bridge" fuel to help society transition toward renewable energy and a hydrogen-based economy.[200] As pressures to address climate issues increase, policy pressures may compound market demands for natural gas, spurring further intensification in its development. This can yield benefits to society, but can also increase both local risks associated with natural gas development, and unintended global consequences in the form of climate impacts as well.[201] Methane, which comprises anywhere from 70 to 98 percent of natural gas,[202] is a much more potent greenhouse gas than carbon dioxide (CO_2), with a CO_2 equivalent of 19.1.[203] Some studies have suggested that fugitive emissions from hydraulically fractured wells are much larger than originally estimated,[204] and that such emissions could offset the climate advantages from increased natural gas use.[205]

One can see that the issues surrounding the impacts of air emissions from natural gas extraction are every bit as intricate as those surrounding the impacts to water resources, if not more so. Additionally, as with water issues, there is great need for additional study in the area. As noted in one report,

> "Gaps in the medical literature are profound… There is a paucity of published literature that directly address the health effects of oil and gas

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[197] *Id.* at 83.
[198] EPA, OVERVIEW OF FINAL AMENDMENTS TO AIR REGULATIONS FOR THE OIL AND NATURAL GAS INDUSTRY – FACT SHEET (2012), *available at* http://www.epa.gov/airquality/oilandgas/pdfs/20120417fs.pdf (last visited September 21, 2012).
[199] The NSPS was promulgated at 77 FED. REG. 49490- 49600. The January 1, 2015 compliance date is established by the new 40 C.F.R. § 60.5375(a).
[200] *See, e.g.* Naim H. Afgan, et al., *Multi-criteria Evaluation of Natural Gas Resources*, 35:1 ENERGY POLICY 704-713 (2007).
[201] *See, e.g.*, Robert W. Howarth, Renee Santoro, and Anthony Ingraffea, *Methane and the Greenhouse-Gas Footprint of Natural Gas from Shale Formations – A Letter*, 106 Climatic Change 679-690 (2011).
[202] HYNE, *supra* note 187 at 8.
[203] EPA GREENHOUSE GAS EQUIVALENCIES CALCULATOR, http://www.epa.gov/cleanenergy/energy-resources/calculator.html#results (last visited September 21, 2012).
[204] *See generally* EPA, CLIMATE CHANGE DIVISION, GREENHOUSE GAS EMISSIONS REPORTING FROM THE PETROLEUM AND NATURAL GAS INDUSTRY (2010), *available at* http://www.epa.gov/ghgreporting/documents/pdf/2010/Subpart-W_TSD.pdf (last visited September 21, 2012).
[205] Howarth et al., *supra* note 201 at 688.

> exploration and production. However there is a sizeable scientific literature linking many of the exposures to adverse health outcomes in humans."[206]

This, in turn, leads directly to the conclusion reached by another researcher: "These data show that it is important to include air pollution in the national dialogue on unconventional [natural gas development] that, to date, has largely focused on water exposures to hydraulic fracturing chemicals."[207]

3.4. Waste Issues

Beyond water and air emissions, natural gas production activities generate a number of solid wastes, ranging from the earth extracted out of the wellbore to resides from the processes used to treat the gas before it is transmitted via pipeline. Some of these wastes contain hydrocarbons, metals and other minerals from underground formations.[208] Ordinarily, the Resource Conservation and Recovery Act[209] (RCRA) would regulate the disposition of these wastes. RCRA establishes requirements for the disposal of "solid waste"[210] and imposes higher standards for the handling of "hazardous waste,"[211] establishing what has come to be known as "cradle to the grave" systems to ensure such hazardous wastes are not released to the environment. By the definition of the terms "solid waste" and "hazardous waste" found in RCRA, a number of wastes generated by natural gas exploration and production would satisfy the definition of either or both terms, triggering a number of handling and disposal requirements. However, after extensive EPA studies and debate in Congress , an exemption was made for wastes derived from the exploration and production (E&P) of oil and natural gas. Congress eventually codified the exemption into the RCRA language at 42 U.S.C. § 6921(b)(2)(A): "drilling fluids, produced waters, and other wastes associated with the exploration, development, or production of crude oil or natural gas or geothermal energy shall be subject only to existing State or Federal regulatory programs in lieu of this subchapter." The question then became what EPA considered "waste associated with" E&P operations. Hundreds of pages of agency guidance exist on

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[206] ROXANA WITTER, ET AL., POTENTIAL EXPOSURE-RELATED HUMAN HEALTH EFFECTS OF OIL AND GAS DEVELOPMENT: A WHITE PAPER, 5 (2008), *available at* http://docs.nrdc.org/health/files/hea_08091702a.pdf13 (last visited September 21, 2012).

[207] MacKenzie, et al., *supra* note 188 at 86.

[208] For examples of these wastes, *see* EPA, EXEMPTION OF OIL AND GAS EXPLORATION AND PRODUCTION WASTES FROM FEDERAL HAZARDOUS WASTE REGULATIONS, *available at* http://www.epa.gov/osw/nonhaz/industrial/special/oil/oil-gas.pdf (last visited September 21, 2012).

[209] 42 U.S.C. §§ 6901 – 6992k.

[210] "Solid waste" is defined at 42 U.S.C. § 6903(27) as:

> any garbage, refuse, sludge from a waste treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, including solid, liquid, semisolid, or contained gaseous material resulting from industrial, commercial, mining, and agricultural operations, and from community activities, but does not include solid or dissolved material in domestic sewage, or solid or dissolved materials in irrigation return flows or industrial discharges which are point sources subject to permits under section 402 of the Federal Water Pollution Control Act, as amended (86 Stat. 880), or source, special nuclear, or byproduct material as defined by the Atomic Energy Act of 1954, as amended (68 Stat. 923).

[211] "Hazardous waste" is defined as

> a solid waste, or combination of solid wastes, which because of its quantity, concentration, or physical, chemical, or infectious characteristics may—
> (A) cause, or significantly contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness; or
> (B) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed.

In regulations promulgated under RCRA, EPA defined two basic means of determining if a material meets either of these two criteria. A waste can be considered "hazardous" if it has a hazardous characteristic (based on defined measures of ignitability, corrosivity, reactivity, or toxicity) or appears on one of EPA's lists of wastes deemed hazardous. *See* 40 C.F.R. §§ 261.21-261.24 (characteristics) and 40 C.F.R. §§ 261.31 – 261.33 (listed wastes).

the topic, including two Federal Register entries detailing the exemption[212] and a 40 page "plain English" guide.[213]

Given the voluminous materials regarding what is and is not an exempt E&P waste, this report could include pages on the topic. In the interest of brevity, though, the discussion will focus on the EPA "rule of thumb" for determining if a waste stream is an exempt E&P Waste:[214]

1) Has the waste come from down-hole, *i.e.* was it brought to surface during oil and gas E&P operations?
2) Has the waste otherwise been generated by contact with the oil and gas production stream during the removal of produced water or other contaminants from the product?

While this exemption excludes a broad variety of wastes from federal regulation, it does have limits. Notably, the exemption targets wastes from materials *used* in the exploration and production processes. For example, the exemption would not include unused fracturing fluids, service company wastes, and spilled chemicals.[215]

Exemption of these wastes from RCRA does not preclude states from regulating them, however, and many states have chosen to do so. A number of states have specific statutes or regulations governing the disposition of drill cuttings (often distinguishing between cuttings from drilling operations using water-based versus petroleum-based drilling fluids), drilling fluids, flowback water, and produced water.[216]

3.4.3. Handling Naturally Occurring Radioactive Materials (NORM)

While the public discussion of environmental risks arising from the natural gas extraction process may conjure any number of images, few people picture radioactive materials when they think about natural gas production. However, oil and natural gas production operations necessarily involve some contact with sources of radioactivity.

Naturally Occurring Radioactive Materials, or "NORM" is the term used to describe materials in the environment that emit some level of radiation. In drilling wells, operators frequently run into small amounts of elements that emit radiation, such as radium, thorium, and uranium.[217] Some shales contain elevated levels of these materials due to the absorption of the materials by the organisms embedded in the shales.[218] When these

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[212] *See* 53 Fed. Reg. 25447- 25458, *and* EPA, *supra* note 208.
[213] EPA, *supra* note 208
[214] EPA, *supra* note 208 at 8.
[215] EPA, *supra* note 208 at 11.
[216] GROAT & GRIMSHAW, *supra* note 101 at 118 – 124.
[217] EPA, *supra* note 68 at 35, *citing* J. A. Harper, *The Marcellus Shale—An old "new" gas reservoir in Pennsylvania*, 38:1 PENNSYLVANIA GEOLOGY 2-13 (2008); J.S. Leventhal and J.W. Hosterman, *Chemical and mineralogical analysis of Devonian black shale samples from Martin County, Kentucky; Caroll and Washington Counties, Ohio; Wise County, Virginia; and Overton County, Tennessee*, 37 CHEMICAL GEOLOGY 239-264 (1982); M.L. Tuttle, G.N. Briet, and M. B Goldhaber, *Weathering of the New Albany Shale, Kentucky: II. Redistribution of minor and trace elements*. 24 APPLIED GEOCHEMISTRY 1565-1578 (2009); and F. Vejahati, Z. Xu, and R. Gupta, *Trace Elements in Coal: Associations with Coal and Minerals and their Behavior During Coal Utilization— A Review*. 89 FUEL 904-911 (2010).
[218] *See* K.P. SMITH, ENVIRONMENTAL ASSESSMENT AND INFORMATION SCIENCES DIVISION, ARGONNE NATIONAL LABORATORY, AN OVERVIEW OF NATURALLY OCCURRING RADIOACTIVE MATERIALS (NORM) IN THE PETROLEUM INDUSTRY, 3 (1992).

materials are exposed to oxygen, they can become more mobile and detach from the formation, where they can become entrained in flowback or produced water as well as being brought to the surface in drill cuttings.[219] Some radiation sources are also used for well diagnostics such as x-ray logs, and gamma-ray logs may also use radiation sources as a means to learn more about the geological formations near the wellbore.[220]

Currently, there are no federal regulations dealing with NORM at the radiation levels usually encountered in the natural gas extraction process, although a proposed EPA regulation for the pretreatment of water from shale gas extraction operations would deal with NORM among other substances that may require pretreatment before discharge.[221] Individual states may also regulate the handling and disposal of NORM, though such regulations are often dispersed among a wide array of agencies, ranging from oil and gas agencies to health departments.

3.5 Community and Landowner Issues

Environmental issues capture the majority of public discussions regarding hydraulic fracturing and natural gas extraction, but other issues face communities in areas of natural gas production. Some communities experience explosive growth that, while providing hope in challenging economic times, can also carry unforeseen challenges. This subsection examines these opportunities and challenges.

3.5.1 The "Boomtown" Model

U.S. history tells countless stories of communities at the epicenter of "booms" in resource discovery and development, from gold rushes in California to the Spindletop discovery in Texas. Tales of the overnight fortunes gained by some residents of these communities often overshadow stories of the growth pains associated with the rapid expansion of economic activity in an area. More recent booms afforded economists and sociologists the opportunity to examine all of the dynamics at play in these scenarios, though. These observations gave rise to models that may help communities evaluate a number of contingencies in their development. Scholars increasingly look to this "Boomtown" model to predict the opportunities and challenges faced by communities in areas of intense natural gas development.[222]

The central premise of the Boomtown model is that small communities exposed to intense economic development in one sector may experience a number of economic benefits, but will also face difficulties in consistently advancing with the needs for infrastructure, social services, workforce, and other community resources.[223] While such development may benefit sectors of the community, others may actually be worse off as a result of

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[219] USGS FACT SHEET FS-142-99, NATURALLY OCCURRING RADIOACTIVE MATERIALS (NORM) IN PRODUCED WATER AND OIL-FIELD EQUIPMENT – AN ISSUE FOR THE ENERGY INDUSTRY (1999), available at http://pubs.usgs.gov/fs/fs-0142-99/fs-0142-99.pdf (last visited September 27, 2012).
[220] *See* HYNE, *supra* note 187 at 319-320.
[221] *See* 76 FED. REG. 66286-66304 (October 26, 2011).
[222] The "Boomtown" model does not appear to have a singular origin point, but appears instead to be a synthesis of a number of observations of the boom-and-bust cycle. Jacquet observes that Gilmore's 1976 article appears to be regarded as the best summation of the model. *See* JACQUET, *infra* note 223 at 6.
[223] JEFFREY JACQUET, NERCRD RURAL DEVELOPMENT PAPER NO. 43, ENERGY BOOMTOWNS AND NATURAL GAS: IMPLICATIONS FOR MARCELLUS SHALE LOCAL GOVERNMENTS & RURAL COMMUNITIES, 1-2 (2009).

inflationary pressures, unmet needs for services, or other shortfalls.[224] One author described the problems predicted by the Boomtown model as depicted in the following diagram:

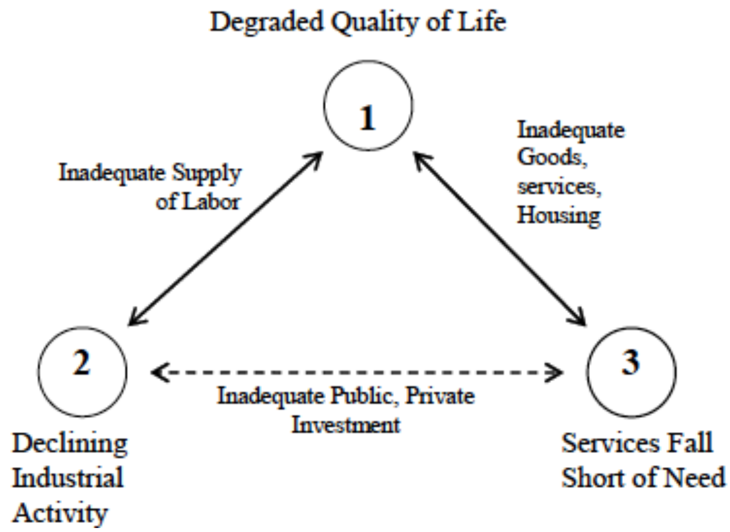

Figure 3-1. Boomtown Model "Problem Triangle"[225]

To succinctly summarize the community challenges predicted by the Boomtown model:[226] A small community may not have the indigenous labor force required to meet the staffing needs of a rapidly-growing industry. This requires "importing" workers from other communities or even other regions. A rapid influx of workers that may reside, at least temporarily, in the community, greatly increases demand for housing, retail services, and schools. The community must then try to respond to these increased demands, but the revenue to do so may lag the increase in demand, thus, causing the community to come up short. This frustrates current and/or new residents, causing some to leave, thus triggering further labor disruptions. As a result of such labor disruptions, or uncertainty in the sustainability of the current situation, productivity and private-sector investment may drop, reducing revenues available to support public-sector financing of needed assets and services. This puts the community even further behind in trying to meet the needs of its stakeholders.

Jacquet, citing Markussen, outlined a number of limitations faced by local governments under the Boomtown model:[227] (1) the development-driving activity may take place in a jurisdiction different than the one bearing the cost of coping with that development, (2) long-term residents may resist funding infrastructure development if they do not perceive that they will benefit from it, (3) the local government may not have jurisdictional

[224] *Id.*
[225] Figure source: *id.* at 7 *citing* J.S. GILMORE AND M. K. DUFF, BOOM TOWN GROWTH MANAGEMENT: A CASE STUDY OF ROCK SPRINGS-GREEN RIVER (1975).
[226] This discussion is adapted from the excerpt of John S. Gilmore, *Boom Towns May Hinder Energy Resource Development: Isolated Rural Communities Cannot Handle Sudden Industrialization and Growth without Help*, 191 *Science* 535-540 (1976), which is quoted in Jacquet, *supra* note 223 at 7-8.
[227] JACQUET, *supra* note 223 at 8-9, *citing* A. Markussen, *Socioeconomic Impact Models for Boomtown Planning and Policy Evaluation,* presented at the Western Regional Science Association Meetings (February 25, 1978).

authority to regulate the activities impacting it, (4) the sheer numbers of people entering the community may make it simply impossible to accommodate the growth without declines in quality of life, (5) boom-bust cycles may make predicting future demand for services difficult, (6) substantial asymmetries of information may exist between the private companies responsible for the development and the communities that must respond to it, and (7) the ever-present element of risk may mean that even seemingly-valid predictions do not come to pass.

The Boomtown model focuses on a number of challenges and problems brought about by rapid economic development; to be sure, positives of increased revenues and employment are to be had as well. These effects are discussed within this section as well.

The effects of rapid growth in one industry, particularly a natural resource development industry, can have impacts on other local industries as well as local governments. Increased competition for labor, higher taxes to pay for increased local infrastructure need, and inflation of asset prices can make other industry segments in the area less competitive, creating what is sometimes called "Dutch Disease" or the "natural resources curse."[228] In some cases, local or regional economies with higher degrees of reliance on natural resource industries can experience lower economic growth compared to comparable economies.[229]

It should be noted that the level of impacts felt or perceived by a community may well depend on the population density and/or geographic isolation of the area. Areas with lower population density, for example, seem to have more awareness of the impacts of a resource-extraction industry's impacts.[230]

3.5.2 Services

Increased area employment intuitively leads to increased use of local services, and in at least some communities in the Marcellus Shale region, this prediction has been validated. A survey of local businesses conducted by Pennsylvania State University in that region indicated increased business volume for restaurants, one-stop gas stations, bars, and retail establishments.[231] At the same time, the survey results also suggested some service facilities faced strains from the growth in activity, with respondents noting insufficient capacity in dining facilities and hotels.[232]

3.5.3. Housing

One sector almost certain to see impacts from significant increases in area economic activity is housing. One study of Sublette County, Wyoming – an area seeing intensive development of the Jonah Field and Pinedale Anticline Field natural gas deposits – found

[228] *See* AMANDA L. WEINSTEIN AND MARK D. PARTRIDGE, THE ECONOMIC VALUE OF SHALE NATURAL GAS IN OHIO, 5 (2011).
[229] *Id., citing* Elissaios Papyrakis and Gerlagh Reye, *Resource Abundance and Economic Growth* 51:4 U.S. EUROPEAN ECONOMIC REVIEW 1011-1039 (2007); Maureen Kilkenny, Maureen and Mark D. Partridge, *Export Sectors and Rural Development* 91 AMERICAN JOURNAL OF AGRICULTURAL ECONOMICS 910-929 (2009); and Alex James and David Aadland, *The Curse of Natural Resources: An Empirical Investigation of U.S. Counties,* 33:2 RESOURCE AND ENERGY ECONOMICS 440-453 (2011).
[230] *See* Kathryn Brasier, *et al*, *Residents' Perceptions of Community and Environmental Impacts from Development of Natural Gas in the Marcellus Shale: A Comparison of Pennsylvania and New York Cases*, 26:1 JOURNAL OF RURAL SOCIAL SCIENCES 32-61 (2011).
[231] PENNSYLVANIA STATE UNIVERSITY COOPERATIVE EXTENSION, DOWNTOWN BUSINESS COMMUNITIES AND MARCELLUS SHALE DEVELOPMENT IN PENNSYLVANIA," 2 (2011), a*vailable at h*ttp://pubs.cas.psu.edu/freepubs/PDFS/EE0012.pdf (last visited September 27, 2012).
[232] *Id.*

that house values increased by more than 150 percent in most areas of the county between 2000 and 2007, and that average rental rates houses and apartments increased by 128 percent and 97 percent, respectively over the same time frame.[233] Such trends can translate into higher income for those who own rental properties, those selling properties, and those involved in real estate transactional work such as realtors, title agencies, insurers, inspectors, mortgage companies, etc. Increased revenues and property values can also increase local tax revenues. However, rapidly increasing property values and rental rates can also make housing less affordable for those stakeholders who are not employed by the high-growth sector or whose wages are otherwise unable to keep pace with the local inflation. Those on fixed incomes may be especially vulnerable to such pricing trends.[234]

3.5.4. Transportation and Utilities

The hydraulic fracturing process can involve hundreds, if not thousands of truck-trips per wellsite to transport the needed equipment and materials.[235] In areas with intensive use of hydraulic fracturing, significant increases in traffic seem likely. Since these truck-trips usually involve heavy equipment, the increased traffic likely triggers the need for increased repair of roadways and potential reinforcement of bridges or other sensitive road structures. Increased traffic also increases the probability of accidents and the need for emergency response personnel.[236]

Other infrastructure systems beyond roads and bridges require strengthening in rapidly-growing areas as well. As noted above, both water supply and water treatment facilities may face new demands. If housing expands to accommodate the new influx of workers, additional water, sewer, electrical, telecommunications and street systems must connect the new housing. In some cases, these system expansions may be funded by private investment, but in others, public revenues may be required. In some cases, these infrastructure needs may outpace the revenues generated to support them. As one example, the city of Pinedale, Wyoming (part of the Pinedale Anticline Field referenced above) received over $20 million in infrastructure upgrades but has spent all of those revenues on infrastructure upgrades while estimating an additional $30 million is needed for further upgrades.[237]

The strains to infrastructure during a period of rapid expansion in an extractive industry can have significant impacts on both public perception of the issue as well as on local government budgets, as observed in Brasier, *et al* (2011):

> Additionally, increased government spending on social services and infrastructure to accommodate population growth may negate observed

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[233] JACQUET, *supra* note 223 at 36-37, *citing* U.S. CENSUS BUREAU, POPULATION DIVISION, ANNUAL ESTIMATES OF HOUSING UNITS FOR COUNTIES IN WYOMING: APRIL 1, 2000 TO JULY 1, 2007 (2008), *available at* http://eadiv.state.wy.us/pop/cty09hu-est.htm (last visited September 27, 2012), and JACQUET, HOUSING AND REAL ESTATE TRENDS IN SUBLETTE COUNTY, WYOMING 2000 TO 2015 (2007), *available at* http://www.sublettewyo.com/index.aspx?NID=285 (last visited September 27, 2012).

[234] *See, e.g.* Jacquet, *supra* note 223 at 18, *citing* J.S. GILMORE AND M.K. DUFF BOOM TOWN GROWTH MANAGEMENT: A CASE STUDY OF ROCK SPRINGS-GREEN RIVER, WYOMING (1975).

[235] GROAT & GRIMSHAW, *supra* note 101 at 40.

[236] *See* JAQUET, *supra* note 223 at 42.

[237] Jaquet, *supra* note 223 at 40, citing ECOSYSTEM RESEARCH GROUP (ERG) SUBLETTE COUNTY SOCIOECONOMIC IMPACT STUDY (2008), *available at* http://sublette-se.org/files/SubletteProfile11Feb08.pdf (last visited September 27, 2012).

> fiscal gains. Physical infrastructure—housing, roads, water supplies, sewer systems—and community services experience unprecedented strain during 'boom' periods. Rapid, unpredictable growth provides unique planning and fiscal challenges for local municipalities (Cortese and Jones 1977; Markussen 1978). In the Barnett Shale, Theodori (2009) found that eight of the top ten problems noted by residents in early stages of development were related to traffic and damage to roads, environmental quality, and land use.[238]

3.5.5. Employment and Workforce Availability

Jumps in employment can be one of the first community impacts experienced in a resource boom. Growth in energy sector employment has outstripped growth in almost every other sector of the U.S. economy in recent years, standing apart from relatively slow growth or declines in those other sectors.

Employment studies in the Marcellus Shale region underscore this trend. Over the period from the fourth quarter of 2008 to the fourth quarter of 2011, employment in energy-related industries in Pennsylvania rose 159 percent while overall employment declined 1.2 percent.[239] These jobs also offered wages substantially above the average for other industries, with average energy-sector wages reaching approximately $34,100 more per year than the average for other industries.[240] The growth of employment in the energy sector can provide positive impacts for other related sectors as well. The Pennsylvania data for "ancillary industries" (industries that can serve or are closely related to oil and natural gas extraction) showed growth of 2.8 percent over the same timeframe, with an average wage of $16,900 more than the average for other industries.[241] Although the magnitude of these differences in overall employment and wages is different, similar effects have been documented in other natural gas development areas, such as the Sublette County, Wyoming area.[242]

Increased employment and wages in the energy and energy-related sectors can provide obvious benefits for communities, but it can also cause strain to other industries. Inflationary pressures caused by high wages in the energy sector can draw employees out of other sectors and increase the wages other sectors must pay, even if they do not benefit from the activity of the energy sector.[243] Sublette County, Wyoming, and the surrounding area serves as an example of these inflationary pressures; the county reported a compounded inflation rate of 43.78 percent between 2003 and 2008, compared to a national compounded rate of 21.77 percent.[244]

The timing of labor needs for the natural gas extraction industry can pose a challenge to communities as well. At least one study has indicated that a natural gas well requires approximately 13.1 full time employees during its drilling and completion phase, but only

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[238] Brasier, *et al, supra* note 230 at 36.
[239] PENNSYLVANIA DEPARTMENT OF LABOR AND INDUSTRY, MARCELLUS SHALE FAST FACTS: JULY 2012 EDITION, 4, *available at* http://www.marcellus.psu.edu/resources/PDFs/July2012_FastFacts.pdf (last visited September 26, 2012). The term "energy-related" as used here refers to those jobs classified as "core industries" in the referenced publication.
[240] *Id.*
[241] *Id.*
[242] *See* JAQUET, *supra* note 223 at 29-34.
[243] JAQUET, *supra* note 223 at 2.
[244] *Id.* at 35.

0.18 full time employees during its production phase.[245] While communities may strain to provide housing and other services during the drilling phase, they may face sudden drops in demand for those facilities and services in the production phase, leaving "stranded" assets.

The difficulty in accurately measuring the employment impacts of the natural gas industry poses another challenge to the discussion. Wide variation has been shown in studies examining employment impacts in the Marcellus Shale region of Pennsylvania, with estimated employment impacts ranging from 10,000 new jobs to 140,000 depending on the methodologies used.[246] Similarly, estimates of natural gas employment impacts in Colorado, Texas, and Wyoming show that the actual employment levels tended to be below initial estimates.[247]

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[245] TIMOTHY W. KELSEY, ET AL., ECONOMIC IMPACTS OF MARCELLUS SHALE IN PENNSYLVANIA: EMPLOYMENT AND INCOME IN 2009 (2011), *available at* http://www.marcellus.psu.edu/resources/PDFs/Economic%20Impact%20of%20Marcellus%20Shale%202009.pdf, last visited September 26, 2012, *citing* TRACY BRUDNAGE, ET AL., SOUTHWEST PENNSYLVANIA MARCELLUS SHALE WORKFORCE NEEDS ASSESSMENT (2010).

[246] *Compare* AMANDA L. WEINSTEIN AND MARK D. PARTRIDGE, THE ECONOMIC VALUE OF SHALE NATURAL GAS IN OHIO, 12 (2011) (estimating a gain of approximately 10,000 direct and indirect jobs) *with* KELSEY ET AL., *supra* note 245 at 5 (estimating impact of between 23,385 and 23, 884 jobs), *and with* TIMOTHY CONSIDINE, ROBERT WATSON AND SETH BLUMSACK, THE PENNSYLVANIA MARCELLUS NATURAL GAS INDUSTRY: STATUS, ECONOMIC IMPACTS AND FUTURE POTENTIAL. (2011) (indicating a gain of 140,000 jobs) .).

[247] *See* Jeremy G. Weber, *The Effects of a Natural Gas Boom on Employment and Income in Colorado, Texas, and Wyoming*, 34 ENERGY ECONOMICS 1580-1588 (2012).

3.5.6. Locus of Costs and Revenues

As noted throughout this discussion, natural gas extraction activities require a broad range of public infrastructure systems and services, including roads, bridges, water supplies and water waste treatment systems, law enforcement, medical services, education, training, and others. The most intensive use of transportation and utility systems by the industry itself naturally occurs in the immediate vicinity of the extraction activities, though regional impacts may occur as well. Use of infrastructure and services by employees of the industry may depend largely on whether those employees choose to reside in communities near the extraction locations or if they commute to and from those areas (or alternatively, "rotate" into an area for some period – such as a one-week or two-week on-duty period – and then rotate back to their homes for the off-duty period).[248] Thus, determining the locus of costs to be borne by the various units of local, state, and federal government is a function of two factors: (1) the highly location-specific conditions of direct industry use of government-provided infrastructure and services, and (2) the structure used to pay for such services (for example, are the roads predominantly used locally- or state-funded?).

Determining who bears the costs of providing infrastructure and costs is only the first half of the discussion. Determining what unit of government captures the tax revenues generated by natural gas extraction is the second. Revenues generated by natural gas extraction activities may be captured by governments in a number of ways, including sales taxes on goods and services used by the industry, "severance" taxes on the extraction of the resource, royalty or income taxes on payments made to resource owners, personal- or real-property taxes on equipment or real estate involved in the industry, transfer taxes on real property transactions, personal and corporate income taxes, and others. Which governmental unit receives these revenues then depends on two factors as well: (1) the structure for allocating the taxes collected (for example, are transfer taxes collected by the municipality, county, or state?), and (2) the unit having jurisdiction over the taxpayer (for example, does the owner of the minerals paying a royalty tax reside on the property itself or at some distant location [an "absentee" landowner]?).[249]

The combination of these factors can make determining the locus of costs and revenues challenging. Studies by Pennsylvania State University indicate that a number of counties in the Marcellus Shale region with high levels of development activity (more than 150 wells drilled) have indeed seen increased state sales tax collections and reduced negative impacts to real estate transfer taxes relative to other counties.[250] Counties with Marcellus Shale activity also saw higher average state personal income tax collections.[251] While such data provide a positive indication for state revenues, they do not provide any indication of local or school district collections; as noted by the study, "royalty and leasing income is exempt from the local earned income tax and local jurisdictions cannot levy sales taxes."[252] Other studies have also noted that who owns the mineral resources (governments, corporations, private persons) and where they reside can impact revenue collections and the overall economic impact of that income.[253]

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[248] *See, e.g.* Kelsey, *supra* note 245 at 15.

[249] For a discussion of "leakage" based on the residence of the mineral owner, *see* KELSEY et al., *supra* note 245 at 14.

[250] PENNSYLVANIA STATE UNIVERSITY, STATE TAX IMPLICATIONS OF MARCELLUS SHALE: WHAT THE PENNSYLVANIA DATA SAY IN 2010, *available at* http://pubs.cas.psu.edu/FreePubs/pdfs/ua468.pdf, last visited September 26, 2012.

[251] *Id.*

[252] *Id.*

[253] *See generally* Kelsey, *supra* note 245.

Given these factors, a discussion of natural gas extraction activities may need to involve a discussion of whether the current tax structure and/or budget requirements for the governments with jurisdiction in the area allow for capture of revenues from those activities and for their allocation to the jurisdictions where revenues are most needed.

3.5.7. Sociological Impacts

Anytime a sharp increase in population or industrial activity occurs in an area, a number of sociological impacts can arise. Evidence suggests natural gas extraction activities are no exception to this premise. Several studies have shown that increases in natural gas extraction activities correlate to increases in traffic accidents, emergency medical services calls, and arrests.[254] Other concerns resulting from sharp spikes in industrial activity can arise from conflicts between long-term residents and new arrivals to the area in terms of expectations for community development and stresses caused by the rapid growth and/or contraction of economic activity.

At a basic level, residents' perceived quality of life and ties to the community and/or other residents may be affected by a large influx of new residents, which can lead to mental and physical health impacts that eventually trigger crime and substance abuse issues.[255] These and other impacts arrive out of what may be regarded as a subset of the "Boomtown" model: the "disruption hypothesis," which stated that "rapid economic and demographic changes associated with large-scale industrial and resource developments lead inexorably to social and psychological dislocations and to an erosion of established community social structures."[256]

There is a significant amount of literature regarding the sociological impacts from rapid economic development and/or natural resource booms. Increased rates of drug and alcohol use coupled with increased rates of sexually transmitted diseases have been found, particularly in the case of male-dominated and highly mobile workforces.[257] Similarly, increases in crime have also been observed in these conditions, at rates that may be more than proportionate to the levels of population increase.[258] At least part of these issues may arise from the male-dominated and mobile nature of the workforce itself, as its members are away from their own social support structures.[259]

Conversely, the research also suggests that increased efforts to engage both current and new community residents, including these workforces, can alleviate many of these impacts.

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[254] Jaquet, *supra* note 223 at 42, *citing* ERG, SUBLETTE COUNTY SOCIOECONOMIC IMPACT STUDY SUBLETTE COUNTY, WYOMING, *available* http://www.sublettewyo.com/index.aspx?NID=285 (last visited September 27, 2012) and JACQUET, SUBLETTE COUNTY ARRESTS AND INDEX CRIMES 1995-2004 (2005), *available at* http://www.sublettewyo.com/index.aspx?NID=285 (last visited September 27, 2012).

[255] *See* Brasier, *et al, supra* note 230 at 36.

[256] Michael D. Smith, Richard S. Krannich, and Lori M. Hunter, *Growth, Decline, Stability, and Disruption: A Longitudinal Analysis of Social Well-Being in Four Western Rural Counties*, 66:3 RURAL SOCIOLOGY 426 (2001).

[257] *See* S.M. Goldbenberg, J.A. Shoveller, M. Koehoorn and A. Ostry, *And They Call This Progress? Consequences for Young People of Living and Working in Resource-Extraction Communities*, 20:2 CRITICAL PUBLIC HEALTH 157-168 (2010), *citing* S. Goldenberg, J. Shoveller, A. Ostry, and M. Koehoorn, *Sexually transmitted infection (STI) testing among young oil/gas workers: the need for innovative, place-based approaches to STI control*. 99:4 CANADIAN J. OF PUBLIC HEALTH 350–354 (2008); S. Goldenberg, J. Shoveller, A. Ostry, and M. Koehoorn, *Youth sexual behavior in a 'Boomtown': implications for the control of sexually transmitted infections*. 84 Sexually Transmitted Infections 220–223 (2008).

[258] *See* Rick Ruddell, *Boomtown Policing: Responding to the Dark Side of Resource Development*, 5:4 POLICING 328-342 (2011).

[259] Kerry Carrington, Alison McIntosh and John Scott, *Globalization, Frontier Masculinities, and Violence: Booze, Blokes, and Brawls,* 50 BRITISH JOURNAL OF CRIMINOLOGY 407 (2010).

Long-term studies regarding the community impacts of natural resource development are difficult to find, since obtaining meaningful results means having the foresight or fortune to obtain baseline readings in a community before any evidence of the "boom" exists. However, in studies that do have such data, results seem to indicate that community perceptions eventually return to near-baseline levels.[260] These effects may be attributed to long-term adjustments in the perceptions of residents in accepting the changed circumstances as "the new normal."[261]

3.5.8. Landowner Issues

Many discussions of the impacts of natural gas extraction activity omit impacts to the owners of the land containing the resource. The reason why is unclear; perhaps discussants assume that the interests of landowners and operators are aligned and, thus, the impacts to landowners are subsumed in the discussion of impacts to developers, operators while others may not realize ownership of the surface estate may be separate from ownership of the mineral estate.

The validity of the assumption that the interests of the operator and the landowner are aligned depends on the validity of two other assumptions: (1) that the landowner owns both the mineral and surface estates of the property, and (2) that the landowner and operator negotiated a mutually-beneficial agreement free of any asymmetries of information. Though it is impossible to accurately determine how frequently these conditions exist, intuitively one would expect them to be relatively rare.

Ownership of mineral interests is extremely difficult to determine without a deed-by-deed examination of property titles, but significant anecdotal evidence suggests that mineral ownership continues to grow increasingly fractionated as ownership of minerals were in many cases separated generations ago and passed down among multiple children across multiple generations.[262] At least one study has found that "only about half the land in a typical Marcellus county is owned by residents of that county."[263]

Assuming then that natural gas development will frequently involve both a mineral interest owner and a separate, severed surface interest owner, potential impacts to both groups must be considered. Perhaps the greatest concern for mineral interest owners comes from the negotiation of a fair mineral lease. Fortunately, the long history of petroleum development in the United States provides an abundance of literature on the negotiation of mineral rights leases ranging from pamphlets to multi-volume treatises. While this information affords mineral owners and their attorneys a wealth of information from which to draw, it should also be noted that the relatively new technologies employed in natural gas development (like horizontal drilling and hydraulic fracturing) can present challenges that may not have been contemplated by the existing statutes, regulations, or case precedents. To ensure mineral owners can negotiate fair and effective lease agreements, the legal communities in areas of such development must invest time and

[260] *See, e.g.* Smith, *supra* note 256.
[261] *See* Ralph B. Brown, Shawn F. Dorius, and Richard S. Krannich, *The Boom-Bust Recovery Cycle: Dynamics of Change in Social Integration in Delta, Utah¸* 70:1 RURAL SOCIOLOGY 28-49 (2005).
[262] KELSEY ET AL., *supra* note 245 at 4.
[263] KELSEY ET AL., *supra* note 245 at 42.

resources into achieving competence in this area. Additional educational resources may also be needed to help mineral owners understand the issues involved in such negotiations before executing a lease agreement.

Many jurisdictions regard a severed surface estate as a "servient" estate, meaning that the surface must yield to the mineral estate to permit the exploration for and production of oil and gas resources.[264] In such cases, severed surface owners may depend upon the protection provided by surface damage laws prescribing the considerations that such landowners must be afforded. Eight states have enacted such statutes.[265] Most of these states have a long history of oil and gas development. Conversely, states that have only recently seen oil and gas activity have no such statutes. Discussion of such statutes where they do not currently exist may be necessary to reduce conflicts between surface owners, mineral owners, and operators.

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[264] *See, e.g.* Enron Oil & Gas Co. v. Worth, 947 P.2d 610, 613 (Okla. Civ. App. 1997).

[265] NORTH DAKOTA LEGISLATIVE COUNCIL, "SURFACE OWNER PROTECTION ACTS AND OIL AND GAS DEVELOPMENT, 2, *available at* http://www.legis.nd.gov/assembly/61-2009/docs/pdf/19449.pdf (last visited September 26, 2012).