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Hydraulic Fracturing and Water Resources: Separating the Frack from the Fiction

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Executive Summary

Natural gas has been touted by some as a key "bridge fuel" that will transition the United States toward a more low-carbon energy economy. Energy analysts, including the United States Energy Information Administration (U.S. EIA), project that the United States will become increasingly reliant on natural gas. According to U.S. EIA estimates released in January 2012, natural gas production is projected to increase by nearly 30% over the next 25 years, from 22 trillion cubic feet in 2010 to 28 trillion cubic feet in 2035.[1] The growth in natural gas production is driven by a dramatic increase in domestic shale gas production, and by 2021, the United States is projected to be a net exporter of natural gas.

Although extracting natural gas from unconventional sources is more complex and costly than conventional natural gas recovery, technological improvements have made extraction from unconventional sources more economically viable in recent years. In particular, the combination of horizontal drilling and hydraulic fracturing has greatly increased the productivity of natural gas wells. These new techniques, however, have raised concerns about the adverse environmental and social impacts of these practices, especially related to impacts on water resources.

Hydraulic fracturing, or fracking, refers to the process by which a fluid – a mix of water, sand, and chemical additives – is injected into wells under high pressure to create cracks and fissures in rock formations that improve the production of these wells. Hydraulic fracturing was first developed in the early 20th century but was not commercially applied until the mid-to-late 1940s. Hydraulic fracturing is standard practice for extracting natural gas from unconventional sources, including coalbeds, shale, and tight sands, and is increasingly being applied to conventional sources to improve their productivity. It has been reported that hydraulic fracturing is used on 90% of all oil and gas wells drilled in the United States, although insufficient data are available to confirm this estimate.[2]

Hydraulic fracturing has generated a tremendous amount of controversy in recent years. There are daily media reports on this topic from outlets across the United States and in a host of other countries, including Canada, South Africa, Australia, France, and England. It is hailed by some as a game-changer that promises increased energy independence, job creation, and lower energy prices. Others are calling for a temporary moratorium or a complete ban on hydraulic fracturing due to concern over environmental, social, and public health concerns.

To better identify and understand what the key issues are, the Pacific Institute conducted extensive interviews with a diverse group of stakeholders, including representatives from state and federal agencies, academia, industry, environmental groups, and community-based organizations from across the United States. This paper provides a short summary of the key

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[1] U.S. Energy Information Administration (U.S. EIA). 2012. *Annual Energy Outlook 2012 Early Release Overview*. http://www.eia.gov/forecasts/aeo/er/pdf/0383er(2012).pdf.

[2] Carrillo, V. 2005. *Testimony Submitted by Victor Carrillo, Chairman, Texas Railroad Commission Representing the Interstate Oil and Gas Compact Commission*. http://archives.energycommerce.house.gov/reparchives/108/Hearings/02102005hearing1428/Carrillo.pdf.

issues identified in the interviews and in an initial assessment and synthesis of existing research. It especially examines the impacts of hydraulic fracturing and unconventional natural gas extraction on water resources and identifies areas where more information is needed. Our focus throughout the report is on shale gas, although we discuss other unconventional natural gas sources where information is readily available. For the purpose of this report, we use a broad definition of hydraulic fracturing to include impacts associated with well construction and completion, the hydraulic fracturing process itself, and well production and closure.

Despite the diversity of viewpoints among those interviewed, there was surprising agreement about the range of concerns and issues associated with hydraulic fracturing. Interviewees identified a broad set of social, economic, and environmental concerns, foremost among which are impacts of hydraulic fracturing on the availability and quality of water resources. In particular, key water-related concerns identified by the interviewees included (1) water withdrawals; (2) groundwater contamination associated with well drilling and production; (3) wastewater management; (4) truck traffic and its impacts on water quality; (5) surface spills and leaks; and (6) stormwater management.

Much of the media attention about hydraulic fracturing and its risk to water resources has centered on the use of chemicals in the fracturing fluids and the risk of groundwater contamination. The mitigation strategies identified to address this concern have centered on disclosure and, to some extent, the use of less toxic chemicals. Risks associated with fracking chemicals, however, are not the only issues that must be addressed. Indeed, interviewees more frequently identified the overall water requirements of hydraulic fracturing and the quantity and quality of wastewater generated as key issues.

Most significantly, a lack of credible and comprehensive data and information is a major impediment to identify or clearly assess the key water-related risks associated with hydraulic fracturing and to develop sound policies to minimize those risks. Due to the nature of the business, industry has an incentive to keep the specifics of their operations secret in order to gain a competitive advantage, avoid litigation, etc. Additionally, there are limited number of peer-reviewed, scientific studies on the process and its environmental impacts. While much has been written about the interaction of hydraulic fracturing and water resources, the majority of this writing is either industry or advocacy reports that have not been peer-reviewed. As a result, the discourse around the issue is largely driven by opinion. This hinders a comprehensive analysis of the potential environmental and public health risks and identification of strategies to minimize these risks.

Finally, the dialog about hydraulic fracturing has been marked by confusion and obfuscation due to a lack of clarity about the terms used to characterize the process. For example, the American Petroleum Institute, as well as other industry groups, using a narrow definition of fracking, argues that there is no link between their activities and groundwater contamination, despite observational evidence of groundwater contamination in Dimock, Pennsylvania and Pavillion, Wyoming that appears to be linked to the integrity of the well casings and of wastewater storage. Additional work is needed to clarify terms and definitions associated with hydraulic fracturing to support more fruitful and informed dialog and to develop appropriate energy, water, and environmental policy.

Hydraulic Fracturing and Water Resources: Separating the Frack from the Fiction

Introduction

Natural gas has been touted by some as a key "bridge fuel" that will transition the United States toward a more low-carbon energy economy. Energy analysts, including the United States Energy Information Administration (U.S. EIA), project that the United States will become increasingly reliant on natural gas. According to U.S. EIA estimates released in January 2012, natural gas production is projected to increase by nearly 30% over the next 25 years, from 22 trillion cubic feet in 2010 to 28 trillion cubic feet in 2035. The growth in natural gas production is driven by a dramatic increase in domestic shale gas production, and by 2021, the United States is projected to be a net exporter of natural gas (U.S. EIA 2012).

Although extracting natural gas from unconventional sources is more complex and costly than conventional natural gas recovery, technological improvements have made extraction from unconventional sources more economically viable in recent years. In particular, the combination of horizontal drilling and hydraulic fracturing has greatly increased the productivity of natural gas wells. These new techniques, however, have raised concerns about the adverse environmental and social impacts of these practices, especially related to impacts on water resources.

To better identify and understand what the key issues are, the Pacific Institute conducted extensive interviews with a diverse group of stakeholders, including representatives from state and federal agencies, academia, industry, environmental groups, and community-based organizations from across the United States. This paper provides a short summary of the key issues identified in the interviews and in an initial assessment and synthesis of existing research. It especially examines the impacts of hydraulic fracturing and unconventional natural gas extraction on water resources and identifies areas where more information is needed.

Overall, we find that the lack of credible and comprehensive data and information is a major impediment to a robust analysis of the real concerns associated with hydraulic fracturing. Due to the nature of the business, members of the industry have an incentive to keep the specifics of their operations secret in order to gain a competitive advantage, avoid litigation, etc. Additionally, peer-reviewed, scientific information on the process and its environmental impacts is lacking. This hinders a comprehensive analysis of the potential environmental and public health risks and strategies to minimize these risks. While much has been written about the interaction of hydraulic fracturing and water resources, the majority of this writing is either industry or advocacy reports that have not been peer-reviewed (U.S. EPA 2011a). As a result, the discourse around the issue to date has been marked by opinion and obfuscation.

BOX 1: DEFINING THE ISSUE

There is a general disagreement about what is meant by "hydraulic fracturing." At least half of the interviewees noted the importance of defining the term when talking about hydraulic fracturing; several others asked for clarification on our definition at the start of the interview. This issue has come up repeatedly in the media as well as in the regulatory process.

Some, including industry representatives, define hydraulic fracturing narrowly, referring only to the process by which fluids are injected into a wellbore. They argue that some of the challenges, e.g., wastewater disposal, spills, leaks, are common to all oil and gas operations and therefore are not specifically associated with hydraulic fracturing. Comments on the proposed Environmental Protection Agency (EPA) study frequently cited problems with the definition of hydraulic fracturing, with industry groups arguing for a narrower definition of the study's scope. For example, the American Petroleum Institute commented that the EPA study plan "confuses hydraulic fracturing and its associated stages" (American Petroleum Institute 2011).

Others, however, define the issue more broadly to include impacts associated with well construction and completion, the hydraulic fracturing process itself, and well production and closure (U.S. EPA 2011a, ProPublica 2012). For these groups, hydraulic fracturing and unconventional natural gas production are synonymous with one another because hydraulic fracturing has allowed for the development of these unconventional natural gas resources. Without hydraulic fracturing, shale gas production would be severely constrained, or even nonexistent.

For the purposes of this analysis, we use a broader definition of hydraulic fracturing to include impacts associated with well construction and completion, the hydraulic fracturing process itself, and well production and closure.

To date, much of the debate about hydraulic fracturing has centered on the use of chemicals and concerns that these chemicals could contaminate drinking water. In response, numerous states have passed or are considering regulations requiring natural gas operators to disclose the chemicals used during well injection. Additionally, the Ground Water Protection Council and the Interstate Oil and Gas Compact Commission have established a public website that allows companies to voluntarily disclose water and chemical usage for wells since January 2011 that have been hydraulically fractured, although it is of note that these data are not subject to third-party verification and are not in a format that can be searched or aggregated.

But while chemical disclosure can be useful for tracking contamination, it may not be the most important issue for water resources. Other key issues also deserve major attention and analysis, such as the massive water requirements for hydraulic fracturing and the potential conflicts with other water needs, including for ecosystems and for agriculture. Methane contamination of drinking water wells is also a concern according to some field studies. Finally, there are serious challenges associated with storing, transporting, treating, and disposing of wastewater. More and better research is needed on these critical issues.

Natural Gas

Like all fossil fuels, natural gas originates from organic matter buried under the Earth's surface. Heat, pressure, and bacteria turned this organic matter into oil. In especially deep and hot regions underground, this oil then turned into natural gas (U.S. DOE 2008). Over time, some of this natural gas moved through small pores in the surrounding rock toward the Earth's surface, where it was either released into the atmosphere or trapped by dense clays and rocks that prevented further migration. It is from these trapped deposits that most natural gas is produced today. Natural gas can occur in oil fields (known as associated gas); in coal seams (known as coalbed methane); in sandstone or shale; or be present in natural gas fields not associated with oil or coal (known as non-associated gas) (USGS 2002).

Natural gas is commonly classified as conventional or unconventional (Figure 1). Conventional natural gas is generally held as a pocket of gas ***beneath*** a rock layer with low permeability and flows freely to the surface once the well is drilled. By contrast, unconventional natural gas is more difficult to extract because it is trapped ***in*** rock with very low permeability. Unconventional natural gas does not flow freely to the surface once the well is drilled. Three common types of unconventional gas include: (1) coalbed methane, which is sourced from within a coal seam or in the surrounding rock; (2) tight natural gas, which is found in low-porosity sandstones and carbonate reservoirs; and (3) shale gas, which is trapped in the pore space of shale rocks.

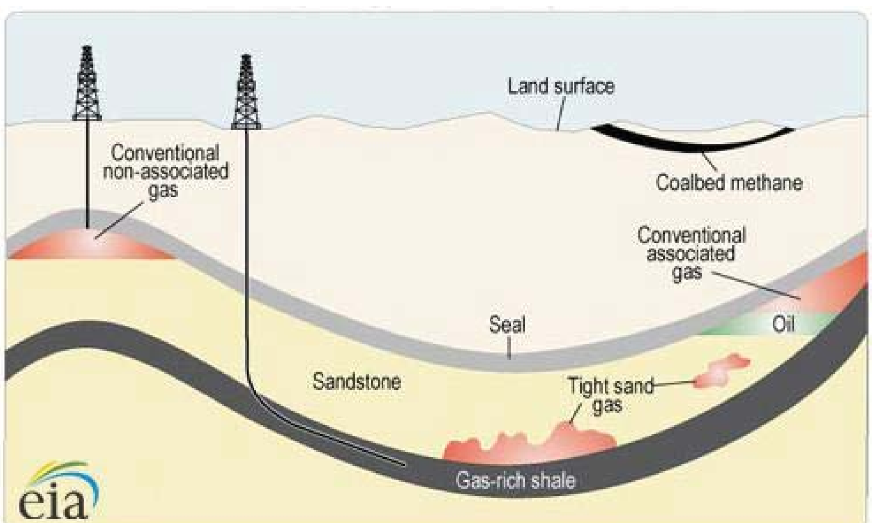


Figure 1. Types of natural gas, including non-associated gas, tight gas, associated gas, shale gas, and coalbed methane
Source: U.S. EIA 2011a

Historically, natural gas production from unconventional reserves has been limited. In 1990, unconventional resources in the United States accounted for 2.6 trillion cubic feet of natural gas per year, or about 15% of total production (Figure 2). By 2035, U.S. EIA analysts project that annual production from unconventional sources in the United States will increase to 21 trillion cubic feet per year and represent 77% of total natural gas production (U.S. EIA 2012). Shale gas accounts for the vast majority of growth in natural gas production, although some growth is also projected for tight gas. By contrast, natural gas production from conventional resources is projected to decline during this period (U.S. EIA 2012).

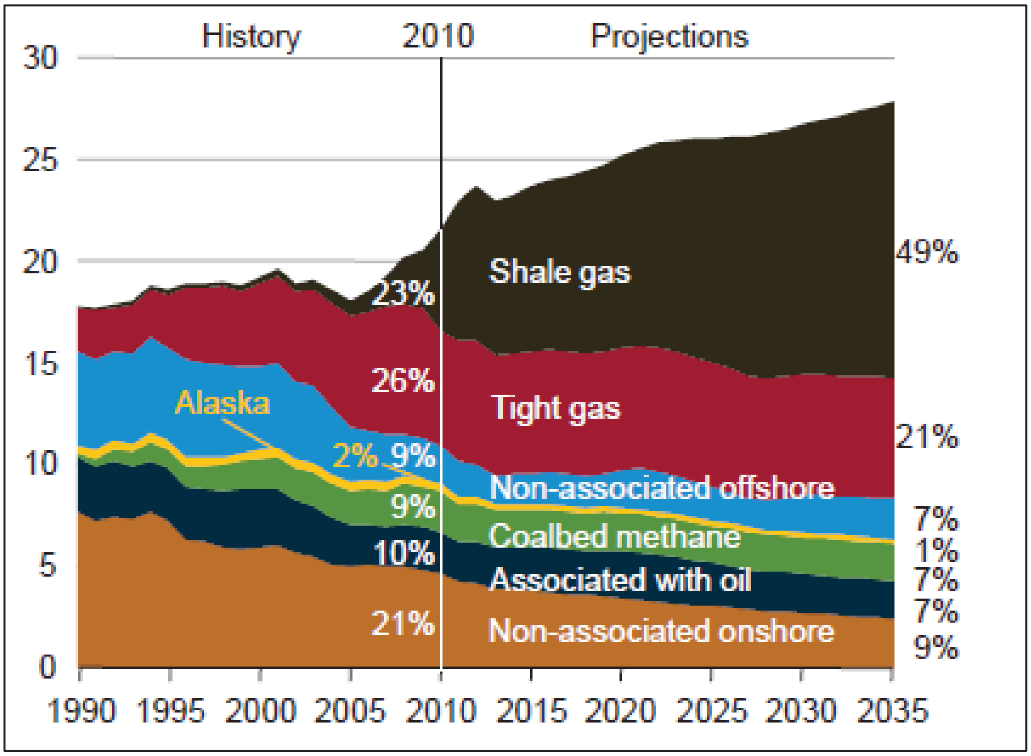
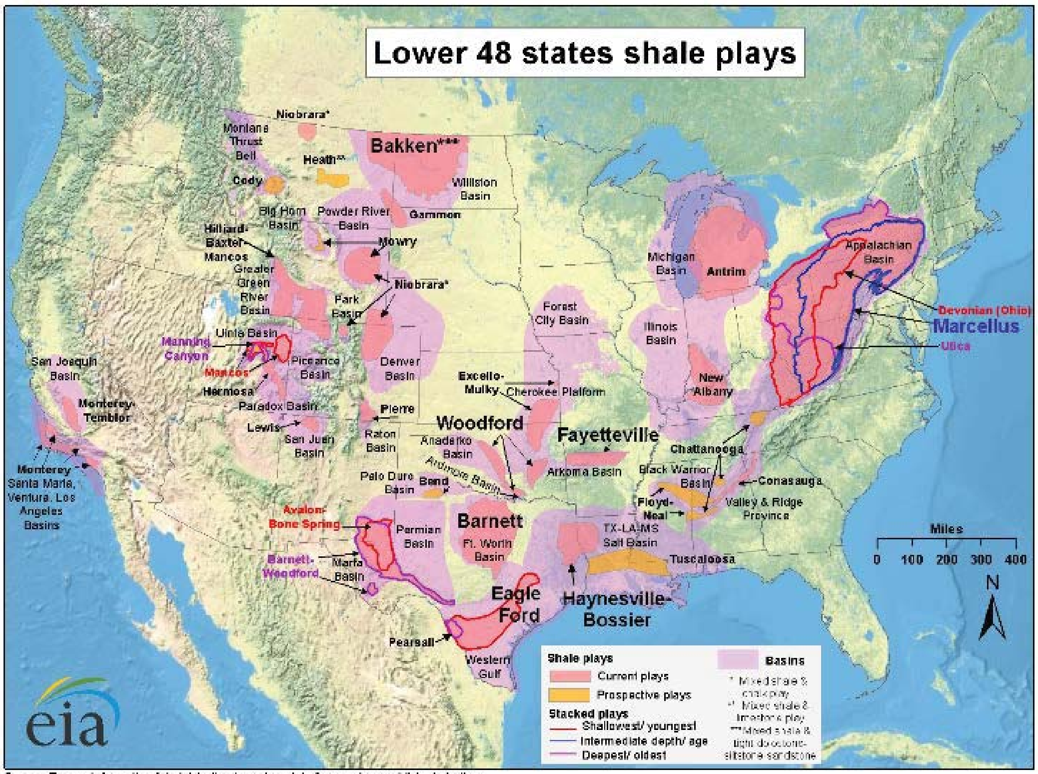


Figure 2. U.S. natural gas production (trillion cubic feet) by source, 1990-2035
Source: U.S. EIA 2012

The rapid development of unconventional natural gas resources has been largely facilitated by the use of directional drilling and hydraulic fracturing. Directional drilling allows for the development of wells that extend vertically for a distance below the Earth's surface and then extend horizontally through the target formation. The horizontal section of the well greatly increases exposure to formations containing natural gas compared to conventional vertical wells. Hydraulic fracturing, described in detail below, further improves the productivity of these wells. Together, these technologies have allowed for exploitation of a resource that had previously been uneconomical.

Unconventional natural gas reserves are located across the United States, as shown in Figures 3 through 5. Currently, about 19 states are producing natural gas from shale and coalbed methane fields, although others are expected to be developed in the future (U.S. EIA 2010). Overall, shale gas has the widest distribution and is found in states throughout the western, midwestern, and northeastern United States. Coalbed methane and tight gas are less widely distributed but are generally found in the same regions as shale gas.

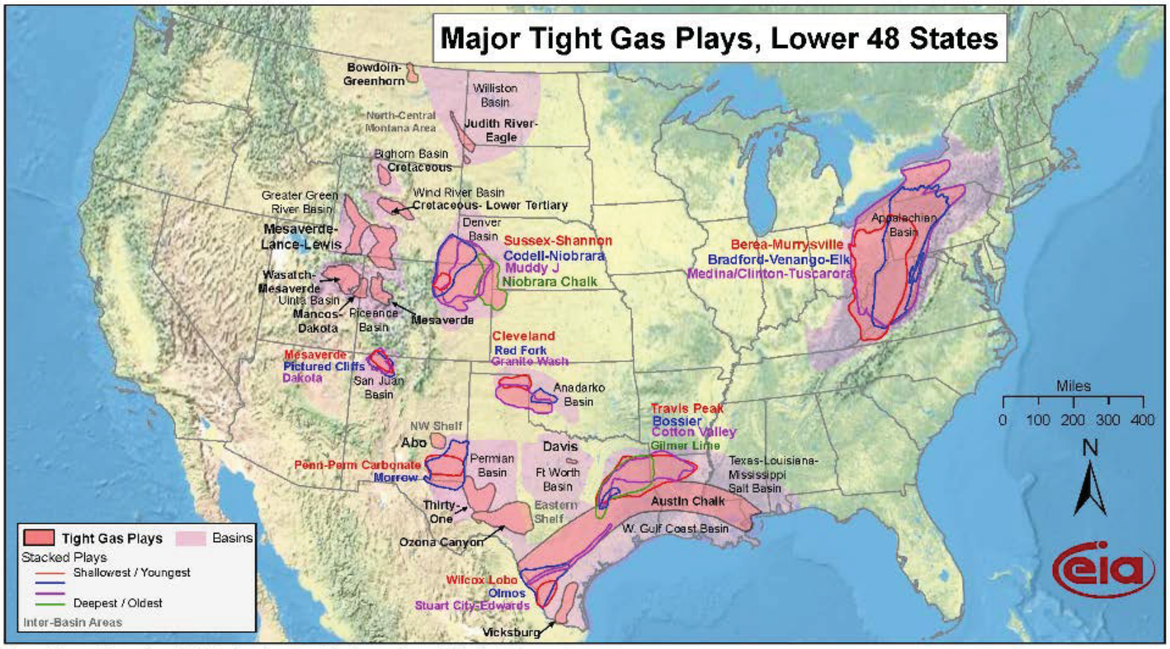
Unconventional natural gas reserves are located at varying depths below ground. In Texas' Barnett and Haynesville/Bossier plays, for example, the natural gas producing areas are thousands to 12,000 feet below ground.[3] In Michigan's Antrim play and in Illinois' New Albany play, the natural gas producing areas are much shallower, ranging from hundreds of feet to 2,000 feet below ground (Arthur et al. 2008). Coalbed methane tends to be found at shallower depths, ranging from several hundred to more than 10,000 feet below ground (U.S. EPA 2011a). Tight gas, by contrast, is generally found at greater depths, from 5,000 to more than 15,000 feet below ground (Anon. 2005).



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

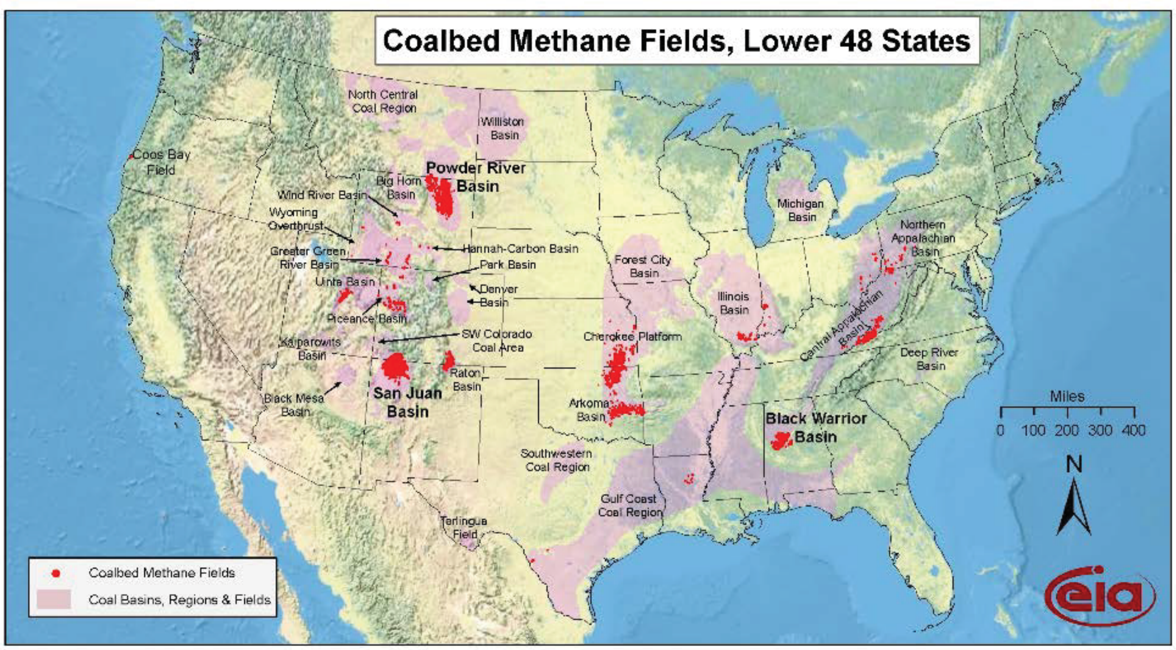
Figure 3. U.S. shale gas plays
Source: U.S. EIA 2011b

[3] The term "play" is used in the oil and gas industry to refer to a geographic area that has been targeted for exploration.



Source: Energy Information Administration based on data from various published studies
Updated: June 6, 2010

Figure 4. U.S. tight gas plays
Source: U.S. EIA 2011b



Source: Energy Information Administration based on data from USGS and various published studies
Updated: April 8, 2009

Figure 5. U.S. coalbed methane plays
Source: U.S. EIA 2011b

Overview of Hydraulic Fracturing

Hydraulic fracturing, or fracking, refers to the process by which fluid is injected into wells under high pressure to create cracks and fissures in rock formations that improve the production of these wells. These fissures can extend up to 1,000 feet from the well (Veil 2010). The fracturing fluid consists of water, chemical additives, and a propping agent. The propping agent – typically sand, ceramic beads, or other incompressible material – holds open the newly created fissures to allow the natural gas to flow freely to the surface. In the first few days to weeks after completion of the fracturing process, the well pressure is released and some of the fracturing fluid (referred to as flowback) flows back to the surface through the wellbore. Some unknown volume of fracturing fluid, along with its chemical additives, remains underground. Over longer time periods, any water naturally present in the ground (referred to as produced water) continues to flow through the well to the surface. The flowback and produced water, which can be considerably saltier than seawater and contain a variety of other contaminants (IOGCC and ALL Consulting 2006), are typically stored on site in tanks or pits before reuse or disposal. There are varying and conflicting reports on whether and to what extent wells will be refracked (Nicot et al. 2011), although this will likely depend on the local geology, spacing of wells, and natural gas prices.

Hydraulic fracturing was first developed in the early 20th century but was not commercially applied until the mid-to-late 1940s. Although initially developed to improve the production of oil and gas wells, hydraulic fracturing has been used in other applications, including developing drinking water wells (NHDES 2010), disposing of waste, and enhancing electricity production from geothermal energy sources.[4] Hydraulic fracturing is standard practice for extracting natural gas from unconventional sources, including coalbeds, shale, and tight sands, and is increasingly being applied to conventional sources to improve their productivity. While the process is the same, the various applications of hydraulic fracturing differ in their water requirements, the amount and types of chemicals employed, and the quantity and quality of wastewater generated. According to a Congressional testimony from a representative of the Interstate Oil and Gas Compact Commission, a multi-state government agency, hydraulic fracturing is used on 90% of all oil and gas wells drilled in the United States (Carrillo 2005), although insufficient data are available to confirm this estimate.

Concerns Associated with Hydraulic Fracturing Operations

The dramatic increase in hydraulic fracturing operations over the past few years has generated a growing amount of controversy. There are daily media reports from outlets across the United States and in a host of other countries, including Canada, South Africa, Australia, France, and England, about environmental, social, economic, and community impacts. In an effort to identify the key issues, the Pacific Institute interviewed 16 representatives of state and federal agencies, academia, industry, environmental groups, and community-based organizations in the United States. Their responses are summarized in Figure 6. Although a relatively small sample size, the interviews were extensive, and the detailed responses from these diverse stakeholders are indicative of the broad range of concerns associated with hydraulic fracturing.

[4] Note that chemicals are not used in some of these applications, e.g., for drinking water wells.

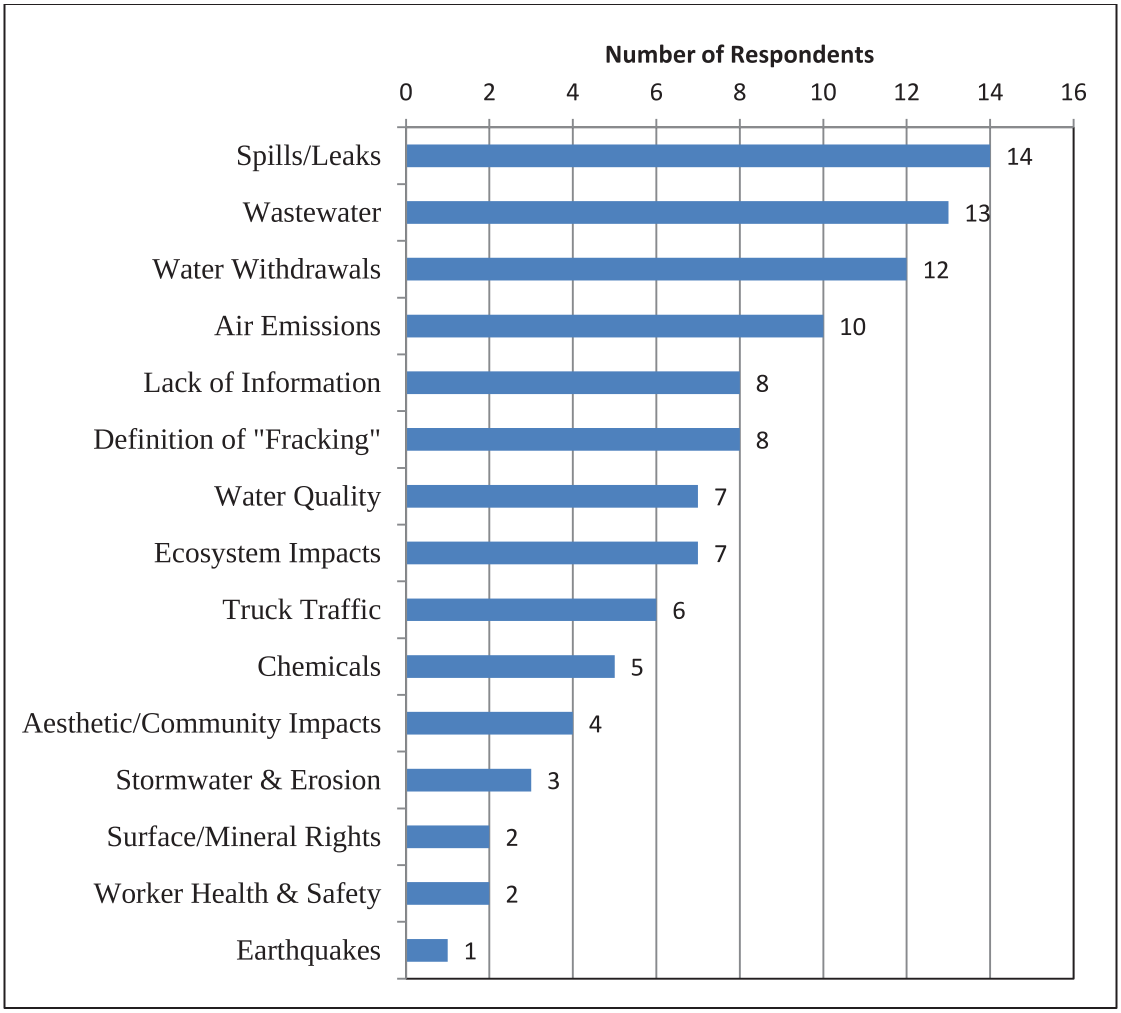


Figure 6. Key concerns identified by interviewees

Note: Results based on interviews with 16 representatives from state and federal agencies, academia, industry, environmental groups, and community-based organizations.

While concerns about impacts on the environment were the most commonly cited, social and economic concerns were also identified, including worker health and safety and aesthetic/community impacts associated with the rapid industrialization of largely rural environments (Figure 7). The top three issues identified by the interviewees included spills and leaks, wastewater management, and water withdrawals. Impacts on air quality were also identified as key concerns by nearly two-thirds of those interviewed. Other issues included water quality, ecosystems/habitat destruction, truck traffic on local roads, and conflicts regarding surface and mineral rights among landowners.

Figure 7. Fracking operation in rural area
Source: Oakridge National Laboratory, 2011

All of the interviewees indicated that impacts on the availability and quality of water resources were among the primary concerns associated with hydraulic fracturing operations. Water-related findings of the interviews include the following:

- Spills and leaks were the most commonly cited concern, with 14 of the 16 people interviewed expressing concern.
- Thirteen of the interviewees considered wastewater treatment and disposal as key challenges. One industry representative noted that wastewater management was perhaps a larger issue than chemical usage.
- Three-quarters of the interviewees were concerned about the water requirements of hydraulic fracturing. This concern was not limited to interviewees in the most arid regions; rather it was expressed by people working in various regions across the United States. In some cases, the concern was directly related to the impacts of large water withdrawals on the availability of water for other uses. But in other cases, concern was related to how large withdrawals would affect water quality.
- Nearly half of the interviewees explicitly identified water quality as a key issue. Many of the other concerns mentioned, e.g., spills, leaks, and wastewater management, also imply concern about water quality. One interviewee expressed concern about surface water contamination associated with air emissions.
- Less than a third of those interviewed specifically identified chemical usage and the associated risk of groundwater contamination as key issues, although many more expressed concern about groundwater contamination more broadly. Some of the interviewees felt that with so much attention given to chemical usage, there is inadequate attention to some of the other issues, such as wastewater disposal and methane migration, which may ultimately pose more serious risks.
- One of the issues identified in our interviews that was not directly related to

environmental impacts was the overall lack of information, with half of those interviewed describing it as a key problem. Several commented on the complexity of the issues and the difficulty explaining the technology to the general public.

Water Resource Challenges

In this section, we summarize the available information on the following key water-related concerns identified by those interviewed: (1) water withdrawals; (2) groundwater contamination associated with well drilling and production; (3) wastewater management; (4) truck traffic and its impacts on water quality; (5) surface spills and leaks; and (6) stormwater management. This information is drawn from a review of the academic and gray literature, media reports, and comments received by the Environmental Protection Agency about the study they have initiated.

Our focus throughout the report is on shale gas, although we discuss other unconventional natural gas sources where information is readily available. For the purpose of this report, we use a broader definition of hydraulic fracturing to include impacts associated with well construction and completion, the hydraulic fracturing process itself, and well production and closure (see Box 1 on page 7 for a brief discussion about defining hydraulic fracturing).

Water Withdrawals

Drilling and hydraulic fracturing a horizontal shale gas well uses large volumes of water, although the amount of water required is both variable and uncertain. The United States Environmental Protection Agency (U.S. EPA) reports that fracturing shale gas wells requires between 2.3 million and 3.8 million gallons of water per well (U.S. EPA 2011a). An additional 40,000 – 1,000,000 gallons is required to drill the well (GWPC and ALL Consulting 2009). This is considerably more water than is required for conventional gas wells and even for coalbed methane because the wells to access shale gas are deeper. Water requirements for hydraulic fracturing of coalbed methane, for example, range from 50,000 to 350,000 gallons per well (U.S. EPA 2011a), although we note that these estimates may be outdated and not include the application of more recent water-intensive processes.

New data, however, suggest that the water requirements for fracking shale gas wells might be both much larger and more variable than is reported by the U.S. EPA (Table 1). For example, Beauduy (2011) finds that fracking in the Marcellus region requires, on average, about 4.5 million gallons per well. Water requirements within Texas' Eagle Ford Shale area can be even greater, where fracking can use up to 13 million gallons of water per well (Nicot et al. 2011), with additional water required to drill the wells. These data highlight the significant variation among shale formations, driven in part by differences in the depth to the target formation and even among wells within close proximity of one another (Nicot et al. 2011). Estimating the water requirements is further complicated by the uncertainty about how many times a single well will be fracked over the course of its productive life and limited publicly-available data.

Table 1. Water requirements for hydraulic fracturing, by shale plays in Texas

Shale Play	Water Requirements (gallons per well)		
	Low Value	Median Value	High Value
Barnett Shale	<1 million	2.6 million	>8 million
Haynesville and Bossier Shale	<1 million	5.5 – 6 million	>10 million
Eagle Ford Shale	1 million	6-6.5 million	13 million
Woodford, Pearsall, and Barnett-PB Shale	<1 million	0.75 – 1 million	<5 million

Source: Estimated based on data in Nicot et al. 2011

Water for hydraulic fracturing is typically withdrawn from one location or watershed over several days (Veil 2010). Additionally, in some cases, the water is taken from "remote, often environmentally sensitive headwater areas" (Beauduy 2011, 34), where even small withdrawals can have a significant impact on the flow regime. As a result, while fracking may account for a small fraction of a state's or even a basin's water supply, there can be more severe local impacts. Additionally, much of the water injected underground is either not recovered or is unfit for further use once it is returned to the surface, usually requiring disposal in an underground injection well. This water use represents a "consumptive" use if it is not available for subsequent use within the basin from which it was extracted. In some cases, water is treated and reused for subsequent fracking jobs, although this is still fairly uncommon, and no national estimate on the prevalence of this practice is available (U.S. GAO 2012).

There is some evidence that the water requirements for hydraulic fracturing are already creating conflicts with other uses and could constrain future natural gas production in some areas. For example, in Texas, a major drought in 2011 prompted water agencies in the region to impose mandatory reductions in water use. Water agencies, some of which sold water to natural gas companies, indicated they might have to reconsider these sales if the drought persisted. Natural gas companies also tried to purchase water from local farmers, offering $9,500 to nearly $17,000 per million gallons of water (Carroll 2011). Likewise, at an auction of unallocated water in Colorado during the spring 2012, natural gas companies successfully bid for water that had previously been largely claimed by farmers, raising concerns among some about the impacts on agriculture in the region and on ecosystems dependent on return flows (Finley 2012).

Concerns over water availability are not limited to drier climates. Pennsylvania is generally considered a relatively water-rich state. However, in August 2011, 13 previously approved water withdrawal permits in Pennsylvania's Susquehanna River Basin were temporarily suspended due to low stream levels; 11 of these permits were for natural gas projects (Susquehanna River Basin Commission 2011). While parts of the state were abnormally dry, the basin was not experiencing a drought at the time, suggesting that natural gas operations are already creating conflict with other uses under normal conditions. In many basins, the application of fracking is still in its infancy and continued development could dramatically increase future water requirements and further intensify conflicts with other uses.

While water withdrawals directly affect the availability of water for other uses, water withdrawals can also affect water quality. For example, withdrawals of large volumes of water can adversely impact groundwater quality through a variety of means, such as mobilizing naturally occurring substances, promoting bacterial growth, causing land subsidence, and mobilizing lower quality water from surrounding areas. Similarly, withdrawals from surface water can affect the hydrology and hydrodynamics of the source water (U.S. EPA 2011a), and reductions in the volume of water in a surface water body can reduce the ability to dilute municipal or industrial wastewater discharges.

Given the proposed expansion of drilling in many regions, conflicts between natural gas companies and other users are likely to intensify. More and better data are needed on the volume of water required for hydraulic fracturing and the major factors that determine the volume, such as well depth and the nature of the geological formation. Additional analysis is needed on the cumulative impacts of water withdrawals on local water availability, especially given that water for hydraulic fracturing can be a consumptive use of water. Finally, more research is needed to identify and address the impacts of these large water withdrawals on local water quality. This work must be done on a basin-by-basin level.

Groundwater Contamination Associated with Well Drilling and Production

Groundwater contamination from shale gas operations can occur through a variety of mechanisms. Natural gas is located at varying depths, often (but not always) far below underground sources of drinking water (Figure 8). The well bore, however, must be drilled through these drinking water sources in order to access the gas. Vibrations and pressure pulses associated with drilling can cause short-term impacts to groundwater quality, including changes in color, turbidity, and odor (Groat and Grimshaw 2012). Chemicals and natural gas can escape the well bore if it is not properly sealed and cased. While there are state requirements for well casing and integrity, accidents and failures can still occur, as was demonstrated by an explosion in Dimock, Pennsylvania (see Box 2 for more information). Old, abandoned wells can also potentially serve as migration pathways (U.S. EPA 2011b) for contaminants to enter groundwater systems. States have estimated that there are roughly 150,000 undocumented and abandoned oil and gas wells in the United States (IOGCC 2008). Natural underground fractures as well as those potentially created during the fracturing process could also serve as conduits for groundwater contamination (Myers 2012). Finally, coalbed methane is generally found at shallower depths and in closer proximity to underground sources of drinking water and therefore accessing the natural gas from this source might pose a greater risk of contamination.

BOX 2: DIMOCK, PENNSYLVANIA

Dimock is located in northeast Pennsylvania's Susquehanna County, the heart of some of the most productive drilling areas in the Marcellus shale play. On New Year's Day in 2009, there was an explosion in an outside drinking water well due to methane build-up in the well. In February 2009, the Pennsylvania Department of Environmental Protection (DEP) issued a notice of violation to the drilling company, Cabot Oil & Gas, which stated that Cabot discharged natural gas into local waterways and failed to prevent natural gas from entering fresh groundwater (PA DEP 2009). Cabot was ordered to install methane detectors in nine homes and provide drinking water to four homes in the affected area (Lobins 2009). Pennsylvania has what is called a "rebuttable presumption" for drinking water pollution, whereby the oil and gas operator is assumed to be responsible for drinking water pollution that occurs within 1,000 feet and within six months of a drilling operation unless the company can provide baseline data to refute the claim. In the absence of baseline data, the company is required to replace the water that has reportedly been lost or degraded (025 Pa. Code §78.51).

The DEP conducted an investigation into the methane contamination and determined that Cabot was responsible for polluting 13 drinking water wells, which was later revised to include an additional five wells (PA DEP 2010). Other violations were also found, including several cases of improper or insufficient casing and excessive borehole pressure. In November 2009, DEP entered into a Consent Order and Settlement Agreement with Cabot that required Cabot to permanently restore or replace water supplies for the affected homes and fix any wells identified to have improper or insufficient casing (PA DEP 2009). Cabot was also ordered to cease drilling in the area and was later completely banned from fracking new or existing wells until authorized by DEP.

Six well owners signed agreements with Cabot and had water treatment systems installed, although most were still using bottled water because they lacked confidence in the treatment systems. Twelve well owners refused to sign agreements with Cabot and were part of a civil suit. Cabot continued to provide temporary water service to these twelve homes. In October 2011, however, the DEP formally stated that Cabot had fully complied with the consent order and was no longer required to provide drinking water to Dimock residents (Legere 2011). DEP allowed Cabot to stop providing water to the twelve homes that had not installed the water treatment systems because Cabot had provided a solution, and well owners were given sufficient time to sign the agreement (U.S. EPA 2011c).

Despite a subsequent announcement in December 2011 from EPA that Dimock water was safe to drink, local residents submitted results from their own testing, which indicated the water was still polluted (McAllister and Gardner 2012). In January 2012, after some vacillation, the EPA began sampling water at approximately 60 homes in the area and supplying drinking water to four households that had shown elevated levels of contaminants that pose a health concern (U.S. EPA 2012). Results of the first round of testing, released in March 2012, indicate that 11 of the homes tested did not have contaminant levels that posed a health concern or exceeded the safe range for drinking water. As of May 2012, results were not yet available for the remaining homes.

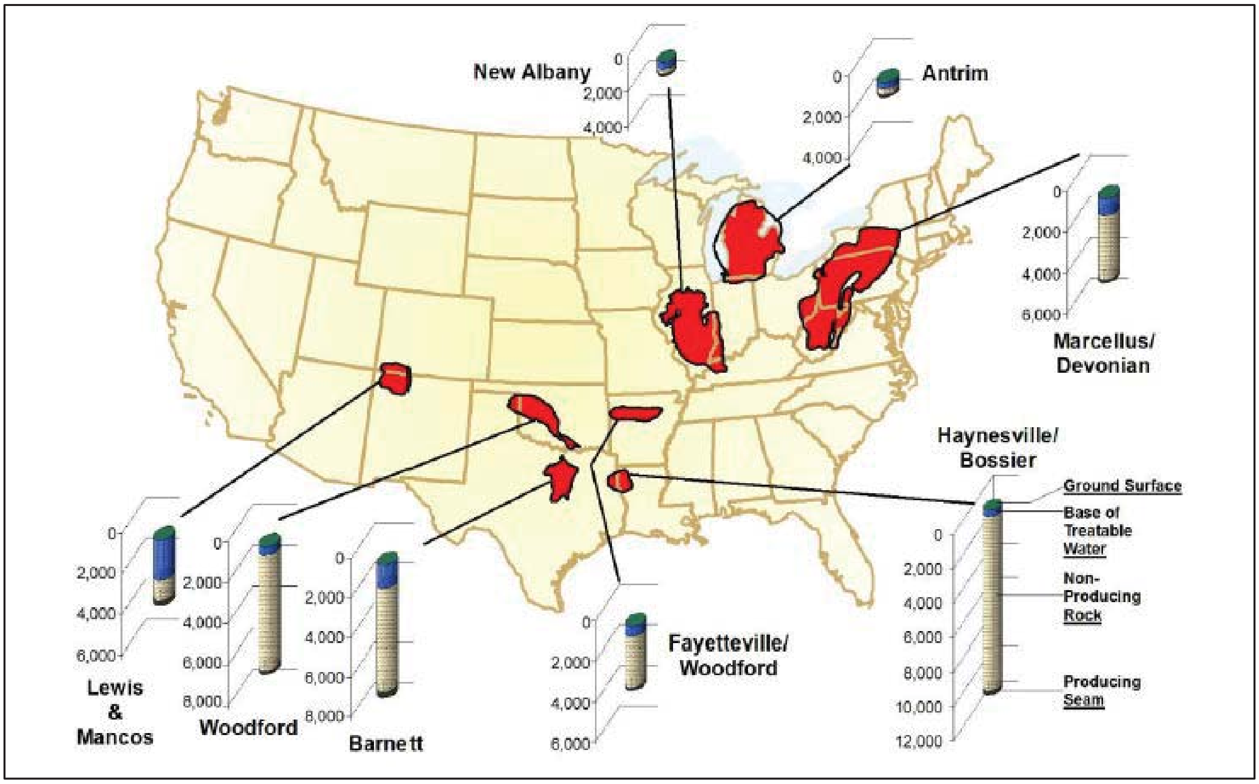


Figure 8. Examples of shale and water table depth
Source: GWPC and ALL Consulting 2009

Much of the debate about groundwater contamination – and some of the most striking visual images showing water and burning natural gas coming out of home faucets – is related to reports of methane contamination in drinking water. Nearly 90% of shale gas is composed of methane. A recent study in New York and Pennsylvania found that methane levels in drinking water wells in active gas production areas (less than 1 km from wells) were 17 times higher than outside of active gas production areas. An isotopic analysis of the methane suggests that the methane in the active gas production areas originated from deep underground (Osborn et al. 2011).

Methane is not currently regulated in drinking water, although it can pose a public health risk. Jackson et al. (2011) note that methane is not regulated in drinking water because it is not known to affect water's potability and does not affect its color, taste, or odor. Methane, however, is released from water into the atmosphere, where it can cause explosions, fires, asphyxiation, and other health or safety problems. The New Year's Day 2009 drinking-water well explosion in Dimock, Pennsylvania, for example, was due to methane build-up in the well associated with natural gas production (see Box 2 for additional information). The Department of the Interior recommends taking mitigative action when methane is present in water at concentrations exceeding 10 milligrams per liter (mg/l) (Eltschlager et al. 2001). A recent study, however, notes that research on the health effects are limited and recommends that "an independent medical review be initiated to evaluate the health effects of methane in drinking water and households" (Jackson et al. 2011, 5).

Figure 9. USGS scientists collecting water samples from discrete fractures.
Source: United States Geophysical Society, 2011

There is also significant concern about groundwater contamination from hydraulic fracturing fluids (see Box 3 for additional information about these fluids), although limited data are available. According to a draft report released in December 2011, however, U.S. EPA testing detected the presence of chemicals commonly associated with hydraulic fracturing in drinking water wells in Pavillion, Wyoming (U.S. EPA 2011b). Encana Oil and Gas, the company responsible for the natural gas wells, disputed the findings of the study, criticizing U.S. EPA's testing methods and assumptions, as well as the processes used to construct and analyze the results of the monitoring wells. In March 2012, U.S. EPA, the state of Wyoming, and the tribes in the region announced that additional sampling would be conducted to provide further clarity on the issue (see Box 4 for additional information).

Real analysis about the likelihood and extent of groundwater contamination is hindered by a lack of baseline data and confusion about definitions. Without baseline data, it is difficult to confirm or deny reports of groundwater contamination. In 2009, regulatory officials submitted signed statements to Congress that stated there are no confirmed cases of groundwater contamination associated with the hydraulic fracturing process (NYSDEC 2011). Likewise, an American Petroleum Institute reports states that "there are zero confirmed cases of groundwater contamination connected to the fracturing operation in one million wells hydraulically fractured over the last 60 years" (American Petroleum Institute 2010). Yet, documented cases in Dimock, Pennsylvania and possibly Pavillion, Wyoming provide evidence of groundwater contamination. In these cases, however, the contamination was associated with well casing integrity and wastewater disposal, not the process of injecting fluids underground per se – and so the issue is clouded by definitions.

BOX 3: FRACKING FLUIDS

Fracking fluids are a complex mixture of many ingredients that are designed to perform a diverse set of functions and accommodate a variety of factors, including local geology, well depth, and length of the horizontal segment of the well. Although the precise recipe is unique to the formation, the fluid is typically composed of proppants (typically sand) to hold open the fractures and allow the natural gas to flow into the well, and chemicals that serve as friction reducers, gelling agents, breakers, biocides, corrosion inhibitors, and scale inhibitors (Figure 10). Industry representatives point out that chemicals represent a small percentage of the fracturing fluid; on average, fracking fluid for shale gas consists of more than 99% water and sand (NYSDEC 2011). Given the large volume of fluid that is injected underground, however, a small percentage can represent a large quantity of chemicals. For example, a 4 million-gallon fracturing job in the Marcellus shale used 937 gallons of hydrochloric acid and 29 gallons of methanol, despite both chemicals representing less than 0.01% of the total fluid by weight (Range Resources, LLC 2010), and some constituents are known to be toxic in extremely small quantities (Colborn 2007).

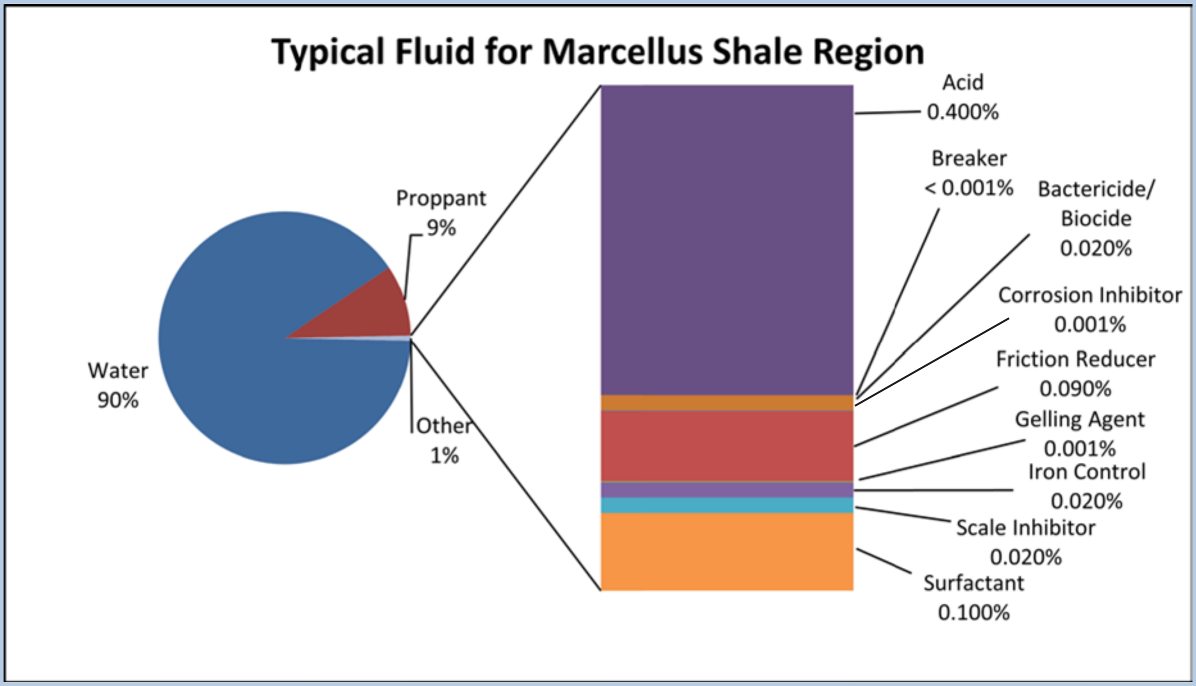


Figure 10. Sample fracturing fluid composition, by weight, from the Marcellus Shale region
Source: NYSDEC 2011

Much of the focus of recent policy and media debates has been on encouraging or requiring the disclosure of the chemical constituents found in fracking fluid. The website FracFocus.org, established by the Ground Water Protection Council (GWPC) and the Interstate Oil and Gas Compact Commission (IOGCC), allows oil and gas drillers to voluntarily disclose the contents of their fracking fluid. In addition, several states have recently updated their regulations to require public disclosure of some information, e.g., Material Safety Data Sheets (MSDS), when certain kinds of toxic chemical additives are used. Other states, including Colorado, Louisiana, Montana, and Texas, have implemented regulations mandating disclosure using FracFocus.org, or a similar program. Few states, however, require the complete disclosure of chemical constituents along with their concentrations and volumes. In addition, some regulations require disclosure to the state rather than to the public, and most allow companies to apply for trade secret exemptions. In Wyoming, for example, 146 chemicals were approved for exemptions as of August 2011, less than a year after the disclosure requirement was implemented (Fugleberg 2011).

BOX 4: PAVILLION, WYOMING

The Pavillion gas field is located in central Wyoming in the Wind River Basin, the upper portion of which serves as the primary source of drinking water for the area. Oil and gas exploration began in the area in the 1950s and increased dramatically between 1997 and 2006. The Pavillion gas field is composed of a mix of sandstone and shale; currently, the field has 169 vertical gas production wells. Encana Oil & Gas owns the rights to the Pavillion field and began drilling in the area in 2004 after acquiring another drilling company. Encana has not drilled any new wells since 2007 (U.S. EPA 2011b).

In 2008, domestic well owners began complaining about taste and odor problems, and residents believed these issues to be linked to nearby natural gas activities. In response to complaints from local residents, the EPA initiated an investigation, collecting four rounds of water samples from 35 domestic wells and two municipal wells between 2009 and 2011. EPA also installed two deep monitoring wells in 2010 and took two rounds of samples from each of these wells. According to a draft report released in December 2011, EPA testing found chemicals commonly associated with hydraulic fracturing in drinking water wells in the area (U.S. EPA 2011b).They also found that dissolved methane concentrations in the domestic wells were higher near the gas production wells. The report concluded that nearby drilling activities “likely enhanced gas migration” (U.S. EPA 2011b).

Encana is disputing the EPA’s preliminary findings. According to Encana, methane is “commonly known” to occur in the shallow groundwater aquifers in the area (Encana Oil and Gas Inc 2011a) and is expected since the Pavillion gas field is also quite shallow (Encana Oil and Gas Inc 2011b). Furthermore, they argue that Pavillion has always had poor water quality, referencing historical reports that levels of sulfate, total dissolved solids, and pH “commonly exceed state and federal drinking water standards” (Encana Oil and Gas Inc 2011a). A 2011 report from the Wyoming Water Development Commission confirms that Pavillion’s water is generally of poor quality and has often had taste and odor problems. However, they state that nearly all of the private wells meet federal and state drinking water standards (James Gores & Associates 2011). One of the challenges associated with the EPA analysis is that baseline data are not available to support claims about impacts on groundwater quality.

Encana continues to dispute the findings of the study, criticizing EPA’s testing methods and assumptions, as well as the processes used to construct and analyze the results of the monitoring wells. Although EPA has indicated intention to submit their report to scientific review, the process is currently on hold as EPA and Wyoming officials re-test the Pavillion monitoring wells (Gardner 2012).

Wastewater Management

Natural gas drilling also produces liquid waste. After completion of the fracturing process, the well pressure is released and some of the fracturing fluid, along with naturally occurring substances, returns to the surface through the wellbore. This mixture – commonly referred to as flowback – returns to the surface over the course of several hours to weeks after the fracturing process is completed (GWPC and ALL Consulting 2009). The amount of fracturing fluid that is actually recovered has not been well quantified. Furthermore, the amount recovered is likely to be highly variable due to local formation characteristics. While various sources quote estimates for the fracture fluid recovery rate (Beauduy 2011; Hoffman 2010; U.S. EPA 2011a), GWPC and ALL Consulting (2009) note that "it is not possible … to differentiate flow back water from natural formation water." Thus, these estimates are likely based on assumptions rather than on actual data.

In addition to flowback, natural gas operations may generate "produced water." Produced water "is any water that is present in a reservoir with the hydrocarbon resource and is produced to the surface with the crude oil or natural gas" (Veil et al. 2004, 1). Produced water can consist of natural formation water, i.e., groundwater; naturally occurring substances, such as radioactive materials, metals and salts; and even some residual fracturing fluid. The physical and chemical properties of produced water depend on the local geology (Veil et al. 2004). Flowback and produced water often have very high total dissolved solids (TDS) levels, in some cases exceeding 200,000 mg/l (Kargbo et al. 2010), nearly three times higher than seawater.[5] In a recent report, the United States Government Accountability Office (U.S. GAO 2012) finds that the volume of produced water generated by a given well varies depending on the type of hydrocarbon produced, the geographic location of the well, and the method of production.

Wastewater resulting from natural gas production is temporarily stored in pits, embankments, or tanks at the well site and then transported, usually via pipeline or truck, to a disposal site (Figure 11).[6] Pits can lead to groundwater contamination, particularly if the pits are unlined or if the integrity of the lining is compromised. In Pavillion, Wyoming, for example, high concentrations of benzene, xylenes, and other organic compounds associated with gasoline and diesel were found in groundwater samples from shallow monitoring wells near pits (U.S. EPA 2011b) (see Box 4 for additional information on Pavillion, Wyoming).

Wastewater from natural gas operations can be disposed of in a variety of manners. In most areas, the primary method of disposing of wastewater from natural gas operations is by injection into a Class II well.[7] In 1988, the U.S. EPA made a determination that oil and gas waste is exempt from hazardous waste regulations under the Resource Conservation and Recovery Act. As a result, oil and gas wastes can be disposed of in Class II wells, rather than in Class I hazardous waste wells.[8] Class II wells are subject to less stringent requirements than Class I

[5] Typical seawater has a TDS concentration of about 35,000 mg/l.
[6] Transportation-related issues are discussed separately, below.
[7] An injection well is a site where fluids, e.g., water, wastewater, brine, or water mixed with chemicals, are injected deep underground into porous rock formations, such as sandstone or limestone, or into or below the shallow soil layer. Injection wells are used for long-term storage, waste disposal, enhancing oil production, mining, and preventing salt water intrusion.
[8] States can adopt for stringent regulations, if desired.

wells and therefore disposal in Class II wells presents a greater risk of contaminating groundwater and triggering earthquakes than in Class I wells (Hammer and VanBriesen 2012). The U.S. EPA estimates that there are about 144,000 Class II wells in operation in the United States, about 20% of which are disposal wells for brine and other fluids from oil and natural gas production. Class II wells might be an onsite well operated by the natural gas company or, more commonly, an offsite well operated by a commercial third-party (Veil 2010). In some cases, wastewater receives partial treatment prior to disposal to avoid clogging the well (Hammer and VanBriesen 2012).

Figure 11. Temporary storage pond used in hydraulic fracturing
Source: National Energy Technology Laboratory, 2011

With the proper safeguards, disposing of wastewater by underground injection reduces the risk of releasing wastewater contaminants into the environment; however, it increases the risks of earthquakes and can require transporting wastewater over long distances (Hammer and VanBriesen 2012). Some states do not have sufficient injection well capacity to handle the volume of wastewater generated from expanding hydraulic fracturing operations, and wastewater is hauled to neighboring states for disposal at a commercial Class II well (Veil 2010). For example, as of late 2010, Pennsylvania had only seven active disposal wells, and some wastewater has been hauled to Ohio, West Virginia, and other states for disposal (STRONGER 2010; Veil 2010).[9]

Flowback and produced water have been treated at a municipal wastewater treatment plant (GWPC and ALL Consulting 2009), although this practice is both uncommon and controversial. These systems are not typically designed to handle this type of wastewater, potentially disrupting the treatment process and discharging salts and other contaminants into the environment. In 2008 and 2009, total dissolved solids (TDS) levels exceeded drinking water standards along the Pennsylvania's Monongahela River, a major source of drinking water – that receives discharges

[9] There are applications for at least 20 additional disposal wells presently before the U.S. EPA (STRONGER 2010).

from facilities handing wastewater from natural gas production (STRONGER 2010). In 2009, excess TDS, primarily from mining discharges, "wiped out 26 miles of stream" in Greene County, Pennsylvania (STRONGER 2010, 22). In response, regulations for new or expanded facilities, including municipal wastewater treatment plants and centralized treatment plants, that accept oil and gas wastewater were passed in 2010 that set strict monthly discharge limits for TDS, chlorides, barium, and strontium (STRONGER 2010). Municipal wastewater treatment plants in Pennsylvania can still receive wastewater from "grandfathered" natural gas operations, although this has now been virtually eliminated (Hammer and VanBriesen 2012).

Wastewater reuse is becoming more common, driven in large part by the challenges associated with wastewater disposal. Reusing wastewater for new fracking activities reduces the total volume of water required, helping to minimize impacts associated with water withdrawals. Wastewater can also be reused for irrigation, dust control on unpaved roads, and deicing roads (U.S. EPA 2011a, Hammer and VanBriesen 2012). In most cases, the wastewater must be treated prior to reuse, but in others it is simply blended with freshwater to bring the levels of TDS and other constituents down to an acceptable range (Veil 2010). Treatment for reuse can occur at the well site using a mobile plant or at a centralized, industrial facility. Some of the downsides of reuse include the need for more onsite storage, energy requirements for the treatment processes, and additional transportation needed to haul wastewater to the treatment plant and among sites. Additionally, concentrated treatment residuals, including brine, must be disposed of in some manner and may require dilution (NYSDEC 2011).

Wastewater treatment and disposal associated with hydraulic fracturing may prove to be a larger issue than some of the other water-related risks. Yet, to date, there has been little discussion about the risks that wastewater treatment and disposal poses. In some areas, it may physically or economically constrain natural gas operations. Additional work is needed to understand the nature of the risk of wastewater treatment and disposal to human health and the environment and to identify where it may constrain natural gas operations.

Truck Traffic

Hydraulic fracturing operations generate a large amount of truck traffic (Figure 12). All of the materials and equipment needed for activities associated with hydraulic fracturing, including water and chemicals, are typically transported to the site by trucks (U.S. EPA 2011a). Additionally, wastewater from natural gas operations is usually removed by tanker truck to the disposal site or to another well for reuse. Using information from the natural gas industry, the New York State Department of Environmental Conservation estimates that high-pressure hydraulic fracturing in a horizontal well would require 3,950 truck trips per well during early development of the well field (NYSDEC 2011), two-to-three-times greater than is required for conventional vertical wells (see Table 2). Much of the truck traffic is concentrated over the first 50 days following well development. Truck traffic could be reduced by nearly 30% if pipelines were used to move water between sites, although pipelines can create other concerns, e.g., leaks, spills, and right-of-way controversies.

Figure 12. Trucks at hydraulic fracturing operations in Virginia
Source: Virginia Department of Mines Minerals and Energy

Truck traffic raises a variety of social and environmental concerns. Trucks increase traffic in the region and create noise and air pollution. Trucks also increase wear and erosions on local roads and the risk of spills, both of which can pollute local surface and groundwater. In addition, because so much of new drilling is occurring in rural locations, new roads must be built to accommodate the truck traffic, increasing habitat fragmentation and ecological disturbances.

Table 2. Truck traffic estimates for vertical and horizontal walls

Well Pad Activity	**Horizontal Well**		**Vertical Well**	
	Heavy Truck	**Light Truck**	**Heavy Truck**	**Light Truck**
Drill pad construction	45	90	32	90
Rig mobilization	95	140	50	140
Drilling fluids	45		15	
Non-rig drilling equipment	45		10	
Drilling (rig crew, etc.)	50	140	30	70
Completion chemicals	20	326	10	72
Completion equipment	5		5	
Hydraulic fracturing equipment	175		75	
Hydraulic fracturing water hauling	500		90	
Hydraulic fracturing sand	23		5	
Produced water disposal	100		42	
Final pad prep	45	50	34	50
Miscellaneous	-	85	0	85
Total one-way, loaded trips per well	1,148	831	398	507
Total Vehicle Trips Per Well	**3,950**		**1,810**	

Note: Light trucks have a gross vehicle weight rating that ranges from 0 to 14,000 pounds. Heavy trucks have a gross vehicle weight rating in excess of 26,000 pounds. The gross vehicle weight is the maximum operating weight of the vehicle, including the vehicle's chassis, body, engine, engine fluids, fuel, accessories, driver, passengers and cargo but excluding that of any trailers.
Source: ALL Consulting (2010) and Dutton and Blankenship (2010), as reported in NYSDEC (2011)

Surface Spills and Leaks

All fossil-fuel extraction activities come with some risk of surface or groundwater contamination from the accidental or intentional release of waste. In the case of hydraulic fracturing, common wastes of concern include fracking fluid, additives, flowback, and produced water. Fluids released onto the ground from spills or leaks can run off into surface water and/or seep into groundwater.

Spills can occur at any stage during the drilling lifecycle. Chemicals are hauled to the site, where they are mixed to form the fracturing fluid. Accidents and equipment failure during on-site mixing of the fracturing fluid can release chemicals into the environment. Above-ground storage pits, tanks, or embankments can fail. Vandalism and other illegal activities can also result in spills and improper wastewater disposal. For example, in Canton Township, Pennsylvania, a January 2012 spill of 20,000 gallons of hydraulic fracturing wastewater is being investigated as "criminal mischief" (Clarke 2012). In a larger incident, criminal charges were filed against a waste hauling company and its owner in March 2012 for illegally dumping millions of gallons of produced water into streams and mine shafts and on properties across southwestern Pennsylvania (Pennsylvania Attorney General 2012). Given the large volume of truck traffic associated with hydraulic fracturing, truck accidents can also lead to chemical or wastewater spills. In December 2011, a truck accident in Mifflin Township, Pennsylvania released fracking wastewater into a nearby creek (Reppert 2011).

While there are reports of spills and leaks associated with hydraulic fracturing operations, the national extent of the problem is not yet well understood. A recent report from Pennsylvania documented a string of violations in the Marcellus region, many of which could result in surface spills and leaks, including 155 industrial waste discharges,162 violations of wastewater impoundment construction regulations, and 212 faulty pollution prevention practices (Pennsylvania Land Trust Association 2010) during the 32-month period from January 2008 to August 2010. New research provides documentation of 24 cases in six states of adverse health impacts on humans, companion animals, livestock, horses, and wildlife associated with natural gas operations, including spills and leaks (Bamberger and Oswald 2012). Additional research is needed on the frequency, severity, cause, and impact of spills associated with hydraulic fracturing.

Stormwater Management

Stormwater runoff carries substances from the land surface into local waterways that can be detrimental to water quality and ecosystem health. While runoff is a natural occurrence, human disturbances to the land surface have increased the timing, volume, and composition of runoff. According to the U.S. EPA, a one-acre construction site with no runoff controls can contribute 35-to-45 tons of sediment each year, comparable to the runoff from 16 acres of natural vegetated meadow (U.S. EPA 2007a; Schueler 1994). Natural gas drilling contributes to this problem, as the process requires disturbances to the land surface. Modern natural gas drilling requires the clearing of seven-to-eight acres per well pad, which includes three-to-four acres for the pad itself, plus additional land for access roads, waste pits, truck parking, equipment, and more (Johnson 2010). Runoff can also contain pollutants from contact with drilling and construction equipment, as well as storage facilities for fracking fluid and produced water.

Stormwater discharges are regulated by state and local governments. The National Pollution Discharge Elimination System (NPDES) program regulates stormwater runoff at the federal level, although states can receive primacy to administer their own permitting program. At the federal level, oil and gas operations have been afforded special protections and are exempt from provisions in the Clean Water Act. Consequently, oil and gas operators are not required to obtain a stormwater permit, unless over the course of operation, the facility generates stormwater discharge containing a reportable quantity of oil or hazardous substances or if the facility violates a water quality standard (40 CFR 122.26(c)(1)(iii)).[10] In 2005, the definition of oil and gas exploration and production was broadened to include construction and related activities, although regulations still require well pads larger than one acre to apply for an NPDES stormwater permit (Wiseman 2012).[11] A 2005 study on the surface water impacts of natural gas drilling noted the difficulty of monitoring and suggested that few facilities were monitoring in a way that would allow them to determine whether they even required an NPDES permit (U.S. EPA 2007b).

Conclusions

Energy analysts project massive increases in domestic natural gas production over the next 25 years. This increase is expected to be largely supplied by unconventional sources, especially shale gas. Although previously too expensive to develop, unconventional natural gas resources have become more economically viable in recent years due to the application of horizontal drilling and hydraulic fracturing. These technological advances have allowed for a rapid expansion of natural gas development both in areas accustomed to natural gas operations as well as in new areas.

Hydraulic fracturing has generated a tremendous amount of controversy in recent years. Hydraulic fracturing is hailed by some as a game-changer that promises increased energy independence, job creation, and lower energy prices. Others have called for a temporary moratorium or a complete ban on hydraulic fracturing due to concern over environmental, social, and public health concerns. There are daily media reports on this topic from outlets across the United States and in a host of other countries, including Canada, South Africa, Australia, France, and England.

In an effort to identify the key issues, the Pacific Institute interviewed a diverse set of representatives of state and federal agencies, academia, industry, environmental groups, and community-based organizations in the United States. Despite the diversity of viewpoints, there was surprising agreement about the range of concerns and issues associated with hydraulic fracturing. Interviewees identified a broad set of social, economic, and environmental concerns, foremost among which are impacts of hydraulic fracturing on the availability and quality of water resources. In particular, key water-related concerns identified by the interviewees included (1) water withdrawals; (2) groundwater contamination associated with well drilling and production; (3) wastewater management; (4) truck traffic and its impacts on water quality; (5) surface spills and leaks; and (6) stormwater management.

[10] This requirement will not be met by sediment discharges alone.
[11] States can implement stronger requirements, if desired.

Much of the media attention about hydraulic fracturing and its risk to water resources has centered on the use of chemicals in the fracturing fluids and the risk of groundwater contamination. The mitigation strategies identified to address this concern have centered on disclosure and, to some extent, the use of less toxic chemicals. Risks associated with fracking chemicals, however, are not the only issues that must be addressed. Indeed, interviewees more frequently identified the overall water requirements of hydraulic fracturing and the quantity and quality of wastewater generated as key issues.

Most significantly, a lack of credible and comprehensive data and information is a major impediment to identify or clearly assess the key water-related risks associated with hydraulic fracturing and to develop sound policies to minimize those risks. Due to the nature of the business, industry has an incentive to keep the specifics of their operations secret in order to gain a competitive advantage, avoid litigation, etc. Additionally, there are limited number of peer-reviewed, scientific studies on the process and its environmental impacts. While much has been written about the interaction of hydraulic fracturing and water resources, the majority of this writing is either industry or advocacy reports that have not been peer-reviewed. As a result, the discourse around the issue is largely driven by opinion. This hinders a comprehensive analysis of the potential environmental and public health risks and identification of strategies to minimize these risks.

Finally, the dialog about hydraulic fracturing has been marked by confusion and obfuscation due to a lack of clarity about the terms used to characterize the process. For example, the American Petroleum Institute, as well as other industry groups, using a narrow definition of fracking, argues that there is no link between their activities and groundwater contamination, despite observational evidence of groundwater contamination in Dimock, Pennsylvania and Pavillion, Wyoming that appears to be linked to the integrity of the well casings and of wastewater storage. Additional work is needed to clarify terms and definitions associated with hydraulic fracturing to support more fruitful and informed dialog and to develop appropriate energy, water, and environmental policy.

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