EXTRACTING HYDROCARBONS FROM UNCONVENTIONAL SHALES
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I. Introduction

The lower 48 states have a wide distribution of hydrocarbon-rich shale formations. Although exploration and production companies have known for many years that hydrocarbons were trapped in these shale formations, those companies lacked the necessary technology to access these resources economically. Two primary factors have come together in recent years to make hydrocarbon production from these shales economically viable—advances in: (1) horizontal drilling; and (2) hydraulic fracturing.1 Numerous commentators have referred to these developments as the “shale revolution.”

Prior to this shale revolution, it was anticipated that the steady decline in U.S. domestic crude oil production would continue into the future and that the U.S. would continue to be heavily dependent on crude oil imports from foreign countries. It was also anticipated that constraints on domestic natural gas production would result in: (1) high prices for consumers; (2) substantial importing of natural gas in the form of liquefied natural gas (“LNG”); and (3) the migration of natural gas using industries—and the jobs that go with them—out of the United States to parts of the world with cheaper supplies.2

The shale revolution has substantially altered that anticipated energy future. The United States now possesses one of the largest oil fields discovered anywhere in the world in the past 30-years—the Bakken/Three Forks Shale located primarily in North Dakota and Montana.3 The United States has become, except for imports from Canada,

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2 See, e.g., To Receive Testimony on the Secretary of Energy Advisory Board’s Shale Gas Production Subcommittee’s 90-day Report Before the S. Comm. on Energy and Natural Resources, 112th Cong. (Oct. 4, 2011) (testimony of Dr. Daniel Yergin, Chairman, IHS Cambridge Energy Research Associates, at p. 2) [hereinafter Yergin Testimony].

3 In 2008, the U.S. Geological Survey estimated that the Bakken/Three Forks Shale contained between 3 to 4.3 billion barrels of undiscovered, technically recoverable oil. See Richard M. Pollastro et
mostly self-sufficient when it comes to natural gas.\textsuperscript{4} In fact, at current production rates, the U.S. Geological Survey estimates that the United States has enough natural gas to supply the country for the next 90-years.\textsuperscript{5} The shale revolution has created several hundred thousand relatively high paying jobs.\textsuperscript{6} Because of the huge success in shale gas development, natural gas prices have fallen substantially—lowering the cost of natural gas-generated electricity and home heating bills.\textsuperscript{7} Natural gas-consuming industries have invested billions of dollars in factories in the United States, something they would not have been expected to do half a decade ago.\textsuperscript{8} The development of shale has created significant new revenue sources for numerous states. For example, as most states were facing massive budget deficits during the most recent recession, North Dakota generated a budget surplus of $1 billion primarily due to revenues generated from hydrocarbon development in that state.\textsuperscript{9}

This shale revolution resulted from a quarter century of technological development, progress, and innovation.\textsuperscript{10} The major breakthroughs came at the end of the 1990s after much disappointment and trial and error.\textsuperscript{11} This paper discusses the process of extracting hydrocarbons from shale-bearing rock and provides an overview of the technological advances that now make it economically viable.

\textsuperscript{4} See, e.g., Yergin Testimony, supra note 2, at p. 2.
\textsuperscript{5} DOE Shale Primer, supra note 1, at p. 3.
\textsuperscript{6} See, e.g., Yergin Testimony, supra note 2, at p. 2.
\textsuperscript{7} Id.
\textsuperscript{8} Id.
\textsuperscript{10} See, e.g., Yergin Testimony, supra note 2, at p. 3.
\textsuperscript{11} Id.
II. **Shale Resources in the United States**

Shales are fine grained, organic rich, sedimentary rocks.\(^{12}\) Hydrocarbons are generated from the organic matter that is deposited with and present in the shales—*i.e.*, pressure and temperature “cook” organic matter into crude oil and natural gas—and much of those hydrocarbons remain trapped in the shale bed.\(^{13}\) Shales have low permeability, which means that the hydrocarbons trapped in the shales cannot move easily within the rock except when natural or artificially created fractures occur.\(^{14}\)

Because of its low permeability, shale is classified as an unconventional reservoir for hydrocarbon production rather than a conventional reservoir.\(^{15}\) In conventional reservoirs, oil and natural gas wells produce from sands and carbonates (limestones and dolomites) that contain the hydrocarbons in interconnected pore spaces that allow flow to the wellbore.\(^{16}\) Much like a kitchen sponge, the hydrocarbons in the pores between the rock grains can move from one pore to another through smaller connecting pore-throats that create permeable flow through the reservoir.\(^{17}\) Where as, in unconventional reservoirs, oil and natural gas wells cannot produce naturally from these low permeability (tight) formations.\(^{18}\) It is typically necessary to stimulate the reservoir to create additional permeability.\(^{19}\) Hydraulic fracturing is the preferred stimulation method for shales,\(^{20}\) and is the only commercial stimulation method that can be applied to a large number of wells over widely scattered geologic areas.

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\(^{13}\) **DOE Shale Primer, supra** note 1, at p. 16.

\(^{14}\) *Id.* at p. 14.

\(^{15}\) *Id.* at p. 15.

\(^{16}\) *Id.*

\(^{17}\) *Id.*

\(^{18}\) *Id.*

\(^{19}\) *Id.*

\(^{20}\) *Id.*
Shale rock containing hydrocarbons is present across much of the lower 48 states. Exhibit 1 below shows the approximate locations of the major shale plays. The six most active shale plays to-date are (in alphabetical order): (1) the Bakken/Three Forks Shale, which is located in the Williston Basin in North Dakota and Montana; (2) the Barnett Shale, which is located in the Fort Worth Basin of north-central Texas; (3) the Eagle Ford Shale, which is located in the Western Gulf Basin in south Texas; (4) the Fayetteville Shale, which is located in the Arkoma Basin in northern Arkansas and eastern Oklahoma; (5) the Haynesville/Bossier Shale, which is located in the North Louisiana Salt Basin in northern Louisiana and eastern Texas; and (6) the Marcellus Shale, which is located in the Appalachian Basin and spans six states in the northeastern United States.

Exhibit 1: Lower 48 States Shale Plays

The shale revolution began in the Barnett Shale where the needed technology was developed. From there, energy companies exported and adapted the technology to other major shale plays within the United States, Canada, and even other parts of the world. At the time of writing of this paper, shale exploration and development is occurring and/or being considered in at least the following countries outside of North America: Argentina, Australia, China, India, the Netherlands, and Poland.

III. Drilling and Completing Shale Wells

As detailed by the American Petroleum Institute, drilling and completing shale wells consists of several sequential activities, including:

- building the location, securing a water source, and installing fluid handling equipment;
- setting up the drilling rig and ancillary equipment and testing all equipment;
- drilling the hole including processes to protect shallow water resources;
- logging the hole (running electrical and numerous other instruments in the well);
- running casing (steel pipe);
- cementing the casing;
- logging and testing the casing;
- removing the drilling rig and ancillary equipment;
- perforating the casing;
- hydraulic fracturing or stimulating the well;
- installing surface production equipment;
- putting the well on production;
- monitoring well performance and integrity; and

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22 See Section III.B.1 infra.

• reclaiming the parts of the drilling location that are no longer needed and removing equipment no longer used.\textsuperscript{24}

It takes approximately 70 to 100 days to drill and complete a typical shale well—four to eight weeks to prepare the site for drilling, four or five weeks of rig work, and two to five days for hydraulic fracturing operations.\textsuperscript{25}

As noted previously, advances in horizontal drilling and hydraulic fracturing make hydrocarbon production from shales economically viable. Those technological advances are discussed below.

A. \textbf{Horizontal Drilling}

Horizontal wells are typically drilled vertically to a point one to two miles below the surface and then redirected to run substantially horizontally for one-half to two miles within the targeted hydrocarbon producing formation.\textsuperscript{26} Exhibit 2 below depicts a typical horizontal well. Horizontal wells offer benefits that improve and allow the economic production of shale formations. Specifically, a long horizontal well section increases the length of the wellbore in the hydrocarbon-bearing formation and therefore increases the surface area for hydrocarbons to flow into the well.\textsuperscript{27} Horizontal wells also allow operators to develop resources with significantly fewer wells than may be required with vertical wells.\textsuperscript{28} Operators can drill multiple horizontal wells from a single surface location, thereby, reducing the cumulative surface impact of the development operation.\textsuperscript{29} However, horizontal wells are significantly more expensive to drill and maintain.\textsuperscript{30}

\begin{itemize}
\item \textsuperscript{26} \textit{API Guidelines}, supra note 24, at p. 4.
\item \textsuperscript{27} \textit{CRS Shale Development}, supra note 12, at p. 20.
\item \textsuperscript{28} \textit{DOE Shale Primer}, supra note 1, at p. 47.
\item \textsuperscript{29} Id.
\item \textsuperscript{30} Id.
\end{itemize}
fact in some areas, the typical cost of a horizontal well may be two to three times the cost of a vertical well.\textsuperscript{31}

\textbf{Exhibit 2: Horizontal Well}\textsuperscript{32}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{horizontal_well_diagram.png}
\end{figure}

1. \textbf{Drilling the Vertical Portion of the Wellbore}

The vertical portion of the well is drilled first. The drill bit is located at the bottom of the drilling pipe lowered by the drilling rig. As the drill bit grinds away, drilling mud or air is pumped down the drill pipe and through the bit to remove rock cuttings from the wellbore.\textsuperscript{33} Next, the drill pipe and bit are removed, and steel pipe called surface casing is inserted into the drilled hole to isolate the fresh water zones.\textsuperscript{34} After the surface casing is in place, cement is pumped down the casing and out through

\begin{thebibliography}{99}
\bibitem{12} \textsuperscript{31} \textit{See id.}
\bibitem{13} \textsuperscript{32} \textit{Source: DOE Shale Primer, supra note 1, at p. 52.}
\bibitem{14} \textsuperscript{33} \textit{SOUTHWESTERN ENERGY, Video of Natural Gas Horizontal Shale Drilling, available at http://www.swn.com/operations/Pages/drillingmethods.aspx (last visited Aug. 9, 2012) [hereinafter Horizontal Shale Drilling].}
\bibitem{15} \textsuperscript{34} \textit{Id.}
\end{thebibliography}
the casing shoe, located at the end of the casing.\textsuperscript{35} The cement moves upward between the surface casing and the wellbore all the way to the surface.\textsuperscript{36} The cementing process seals the wellbore from the surrounding rock and fresh water zones, preventing contamination of fresh water aquifers.\textsuperscript{37} The casing serves as the base that links the well control and safety devices, which are connected to the well and wellbore.\textsuperscript{38} After the cement hardens, the drill pipe and a smaller bit are lowered back down the hole.\textsuperscript{39} The bit drills through the cement at the bottom of the hole and continues to drill the vertical section of the well.\textsuperscript{40}

\section{Drilling the Horizontal Portion of the Wellbore}

At approximately 500 feet above the planned horizontal portion of the well, the drill pipe and bit are pulled out of the well.\textsuperscript{41} Next, the angle building process begins. The angle building process requires a specialized down-hole drill motor, which is powered by the drilling mud—much like air powers a dentist’s drill. The “kickoff point” is where the curve drilling begins to make the transition from a vertical well to a horizontal well.\textsuperscript{42} It takes about 500 to 600 feet to drill the curve from the kickoff point to where the wellbore becomes horizontal.\textsuperscript{43} Once the curve is completed, drilling begins on the horizontal section.\textsuperscript{44}

\begin{itemize}
  \item \textsuperscript{35} Jennifer L. Miskimins, et al., \textit{The Technical Aspects of Hydraulic Fracturing}, 2011 No. 5 ROCKY MTN. MIN. L. INST. PAPER NO. 1, at p. 9 (Nov. 17, 2011).
  \item \textsuperscript{36} \textit{Id.}
  \item \textsuperscript{37} \textit{API Guidelines}, supra note 24, at p. 5.
  \item \textsuperscript{38} \textit{Horizontal Shale Drilling}, supra note 33.
  \item \textsuperscript{39} \textit{Id.}
  \item \textsuperscript{40} \textit{Id.}
  \item \textsuperscript{41} \textit{Id.}
  \item \textsuperscript{42} \textit{Id.}
  \item \textsuperscript{43} \textit{Id.}
  \item \textsuperscript{44} \textit{Id.}
  \item \textsuperscript{45} \textit{Id.}
\end{itemize}
When the well reaches its targeted lateral distance, the drill pipe and bit are removed from the wellbore.\textsuperscript{46} Logging tools are then run into the well to measure various rock and fluid properties plus physical properties of the hole.\textsuperscript{47} This information will be used during the completion stage of the well. Steel pipe, referred to as production casing, is then inserted into the full length of the wellbore.\textsuperscript{48} Cement is pumped into the casing and forced out through the bottom of the casing called the casing shoe.\textsuperscript{49} The cement moves up between the casing and wall of the hole filling the open space known as the annulus.\textsuperscript{50} Upon completion of the cementing process, the production casing is pressure tested to ensure its integrity and is also often logged with specialized tools that measure the integrity of the cement pumped into the annulus.\textsuperscript{51} Casing the well is a very important process, because it permanently secures the wellbore and prevents hydrocarbons and other fluids from seeping out into upper formations as the fluids are brought to the surface.\textsuperscript{52} At this point, there are at least two concentric casing strings, both cemented to ensure that produced fluids and stimulation fluids go only where they are directed.

Once the horizontal portion of the well is drilled, the drilling rig is no longer needed and a temporary wellhead is installed.\textsuperscript{53} The location is then ready for surface crews to prepare the well for production.\textsuperscript{54} The next series of processes are broadly referred to as completing the well. The first step is to perforate the casing.\textsuperscript{55} A

\begin{itemize}
  \item \textsuperscript{46} Id.
  \item \textsuperscript{47} Id.
  \item \textsuperscript{48} API Guidelines, \textit{supra} note 24, at p. 12.
  \item \textsuperscript{49} Id.
  \item \textsuperscript{50} See id.
  \item \textsuperscript{51} Id.
  \item \textsuperscript{52} Id.
  \item \textsuperscript{53} Horizontal Shale Drilling, \textit{supra} note 33.
  \item \textsuperscript{54} Id.
  \item \textsuperscript{55} See API Guidelines, \textit{supra} note 24, at p. 14.
\end{itemize}
perforating gun is used to perforate the casing. The perforating gun is typically pumped down the wellbore to the targeted section of the horizontal leg. Once the perforating gun is in place, workers will send an electrical current down the wire line to the perforating gun. The electric current triggers a series of charges that shoot small holes, i.e., 1/2 an inch, through the casing, through the cement, and out a short distance into the shale formation. This process now connects a specific portion of the production casing to the formation. Workers then remove the perforating gun from the hole. The well is now ready for hydraulic fracturing.

B. Hydraulic Fracturing

Hydraulic fracturing is a formation stimulation practice used to create sufficient permeability in a shale formation, thus allowing hydrocarbons to flow more readily toward the wellbore in commercial quantities. Hydraulic fracturing involves the pumping of a fracturing fluid into a formation at a desired rate and pressure to generate fractures or cracks in the target formation.

1. History of Hydraulic Fracturing

The first commercial hydraulic fracturing treatment was pumped in 1947 on a gas well operated by Pan American Petroleum Corporation in Grant County, Kansas. Since

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56 See id.
57 Horizontal Shale Drilling, supra note 33.
58 Id.
59 Id.
60 Id.
61 See API Guidelines, supra note 24, at p. 15.
62 Id.
that date, close to 2.5 million fracture treatments have been performed worldwide.\textsuperscript{64} And hydraulic fracturing is now used in 90\% of new oil and gas wells.\textsuperscript{65}

The successful application of hydraulic fracturing treatments to shales did not occur until Mitchell Energy experimented with such treatments in the Barnett Shale in the 1980s and 1990s.\textsuperscript{66} Initially, Mitchell Energy attempted expensive and massive hydraulic fracturing projects that pumped very large volumes of thick fluids and heavy sand down the wellbore.\textsuperscript{67} However, any production generated from these fracture treatments quickly declined. In the mid-1990s, Mitchell Energy pioneered the use of slickwater fracture stimulations, which the industry began calling “light sand” fracture stimulations.\textsuperscript{68} By the late 1990s, Mitchell Energy perfected this process in vertical wells, and the industry quickly took notice.\textsuperscript{69}

2. Fracturing Fluids and Proppants

Fracturing fluids used for shale stimulations consist primarily of water, but also include a variety of additives.\textsuperscript{70} The number of chemical additives used in a typical fracture treatment varies depending on the conditions of the specific well being fractured.\textsuperscript{71} A typical fracture treatment will use very low concentrations of between 3 and 12 additive chemicals depending on the characteristics of the water and the shale formation being fractured.\textsuperscript{72} The predominant fluids currently being used for fracture treatments in the shale plays is water mixed with sand and friction-reducing additives

\textsuperscript{64} Carl T. Montgomery and Michael B. Smith, \textit{Hydraulic Fracturing, History of An Enduring Technology}, JOURNAL OF PETROLEUM TECHNOLOGY, at p. 27 (Dec. 2010).


\textsuperscript{67} \textit{Id.}

\textsuperscript{68} \textit{Id.}

\textsuperscript{69} See \textit{id.}

\textsuperscript{70} \textit{DOE Shale Primer, supra} note 1, at p. 61.

\textsuperscript{71} \textit{Id.}

\textsuperscript{72} \textit{Id.}
(called slickwater) to lower the pump pressure.\textsuperscript{73} The other common additive is a biocide to kill bacteria so they cannot get into the formation to begin growing.\textsuperscript{74}

Fracturing fluids are mixed with proppant materials (generally, sand) that are needed to “prop” open the fractures once the pumping of fluids has stopped.\textsuperscript{75} Once the fracture has initiated, additional fluids are pumped into the wellbore to extend the development of the fracture and to carry the proppant deeper into the formation.\textsuperscript{76}

3. Fracturing Process

Hydraulic fracturing of horizontal shale wells is performed in stages.\textsuperscript{77} The horizontal portion of the well, which is referred to as the lateral, may range from 1,000 feet to more than 5,000 feet (Bakken is almost two miles).\textsuperscript{78} Because of that length, it is usually not possible to create enough downhole energy to stimulate the entire length of a lateral at one time.\textsuperscript{79} Instead, hydraulic fracture treatments are usually performed by isolating smaller portions of the lateral. The fracturing of each portion of the lateral is called a stage.\textsuperscript{80} Stages are fractured sequentially beginning with the section at the farthest end of the wellbore (known as the “toe”), moving toward the other end of the lateral (known as the “heel”) until the entire lateral has been stimulated.\textsuperscript{81} A temporary plug is placed in front of each new hydraulically fractured section.\textsuperscript{82} Each plug isolates the hydraulically fractured section of the wellbore so the next section of the horizontal leg

\begin{footnotesize}
\begin{itemize}
\item \textsuperscript{73} Id.
\item \textsuperscript{74} Id.
\item \textsuperscript{75} See API Guidelines, supra note 24, at p. 15.
\item \textsuperscript{76} Id.
\item \textsuperscript{77} DOE Shale Primer, supra note 1, at p. 58.
\item \textsuperscript{78} Id.
\item \textsuperscript{79} Id.
\item \textsuperscript{80} Id.
\item \textsuperscript{81} Id.
\item \textsuperscript{82} Horizontal Shale Drilling, supra note 33.
\end{itemize}
\end{footnotesize}
can be hydraulically fractured. After hydraulic fracturing is completed, the plugs are drilled out, and hydrocarbons are allowed to flow up the wellbore.

Hydraulic fracturing stimulations are overseen continuously by operators and service companies to evaluate and document the events of the treatment process. Every aspect of the fracture stimulation process is carefully monitored, from the wellhead and downhole pressures to pumping rates, concentrations of chemicals used, and density of the fracturing fluid slurry.

Following hydraulic fracturing, operators typically install surface production equipment and restore the portion of the drill site no longer needed to its pre-drilling condition.

4. Controversy Regarding Hydraulic Fracturing

Hydraulic fracturing has generated a great deal of controversy in recent years. Five documentary films have been released on hydraulic fracturing—three pro and two con: Gasland (con), Gas Odyssey (pro), Haynesville (pro), Split Estate (con), and Truthland (pro). Stories on hydraulic fracturing have appeared in countless news media outlets, including print newspapers, magazines, smaller news publications, and blogs. Both the U.S. Senate and House of Representatives have conducted legislative hearings regarding hydraulic fracturing as have many state legislatures. Federal, state, and local regulators across the country are racing each other to regulate hydraulic fracturing, and a variety of interest groups and non-governmental entities are attempting to influence that regulatory process.

The controversy regarding hydraulic fracturing concerns, among other things, allegations that: (1) hydraulic fracturing contaminates groundwater aquifers; (2) fracturing fluids contain many dangerous chemicals; and (3) hydraulic fracturing leads to flammable drinking water.

83 Id.
84 Id.
86 DOE Shale Primer, supra note 1, at p. 60.
87 Horizontal Shale Drilling, supra note 33.
(a) Allegation That Hydraulic Fracturing Contaminates Groundwater Aquifers

Critics of hydraulic fracturing allege that there are documented cases of fracturing fluids migrating into groundwater aquifers that are used for drinking water. The typical evidence cited is complaints from landowners about changes in water quality or quantity following fracturing operations of wells near their homes.\footnote{See, e.g., Earthworks, Hydraulic Fracturing Myths and Facts, at p. 1, available at http://www.earthworksaction.org/files/publications/FS_hydraulic-fracturing_myths-factsFINAL.pdf (last visited Aug. 9, 2012) [hereinafter Earthworks Hydraulic Fracturing].}

The oil and gas industry’s response to such allegations is that hydraulic fracturing is typically conducted at depths of one to two miles below the surface, and solid rock separates the oil and gas deposits from shallow groundwater aquifers.\footnote{See, e.g., Shell, Hydraulic Fracturing Your Questions Answered, at p. 2, available at http://www-static.shell.com/static/usa/downloads/onshore/abc002_hyd_frac_insert0623.pdf (last visited Aug. 9, 2012).} This rock buffer makes contamination from hydraulic fracturing virtually impossible.\footnote{Id.} A commonly cited statistic is that over 1 million wells have been hydraulically fractured in the United States. To-date, there have been no scientifically verified cases of groundwater contamination due to hydraulic fracturing.\footnote{Energy Facts PA, Natural Gas Myths and Facts, available at http://energyfactspa.com/natural-gas/sdefault.asp (last visited Aug. 9, 2012).}

Although the industry acknowledges that there have been some landowner complaints regarding drinking water in areas near oil and gas development, the industry typically attributes such issues to improper disposal of wastewater or resurfacing of wastewater due to poor well design.\footnote{Id.}

Independent studies conducted to-date suggest that contamination of groundwater aquifers from hydraulic fracturing is extremely unlikely. In 2004, the U.S. Environmental Protection Agency released a scientific study concluding that the injection of hydraulic fracturing fluids into coal bed methane wells “poses little or no threat” to
underground sources of drinking water. Similarly, just last year, the U.S. Department of Energy’s Shale Gas Production Subcommittee—whose members were appointed by the Obama Administration—released a report concluding that:

Regulators and geophysical experts agree that the likelihood of properly injected fracturing fluid reaching drinking water through fractures is remote where there is a large depth separation between drinking water sources and the producing zone. In the great majority of regions where shale gas is being produced, such separation exists and there are few, if any, documented examples of such migration.

One of the members of that Subcommittee, Stephen A. Holditch, testified before the U.S. Senate’s Committee on Energy and Natural Resources that “current drilling and hydraulic fracturing activity does not adversely affect shallow drinking water aquifers.”

Similarly, a recent study conducted by the Energy Institute of the University of Texas at Austin found that: (1) there was “no evidence of aquifer contamination from hydraulic fracturing chemicals in the subsurface by fracturing operations” and “no leakage from hydraulic fracturing at depth;” and (2) “[s]urface spills of fracturing fluids appear to pose greater risks to groundwater sources than from hydraulic fracturing itself.”

94 90-day Report, supra note 21, at p. 20.
95 Receive Testimony on the Secretary of Energy Advisory Board’s Shale Gas Production Subcommittee’s 90-day Report Before the S. Comm. on Energy and Natural Resources, 112th Cong. (Oct. 4, 2011) (testimony of Stephen A. Holditch, Head of the Department of Petroleum Engineering, Texas A&M University, at p. 4).
(b) Allegation That Fracturing Fluids Contain Many Dangerous Chemicals

Critics of hydraulic fracturing also allege that fracturing fluid is nothing more than a “toxic brew” of chemicals. At least one environmental group, Earthworks, alleges that the chemicals contained in fracturing fluids have “known negative health effects such as respiratory, neurological and reproductive impacts, impacts on the central nervous system, and cancer.”

The oil and gas industry’s typical response to such allegations is that most fracturing fluids consist of 99.51% water and playground sand and only 0.49% additives. Many of those additives are common chemicals that people regularly encounter in everyday life. Moreover, the industry is in the process of developing entirely “green” fracturing fluids.

Last year, executives from Halliburton Co. publicly demonstrated—in a rather memorable way—that the general public should not fear Halliburton’s fracturing fluids. While speaking at a conference, Chief Executive Officer, Dave Lesar, raised a container of Halliburton’s new fracturing fluids, and then called up a fellow executive to drink it. The executive reported no ill effects after drinking the fracturing fluids.

Independent analysis conducted to-date suggests that most of the chemicals used in fracturing fluids are not harmful. For example, the U.S. Department of Energy has stated that fracturing fluids contain chemical additives that are “safe when properly handled according to requirements and long-standing industry practices” and that “many

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99 See id.
of these additives are common chemicals which people regularly encounter in everyday life."102 Last year, Mark Zoback, a member of the U.S. Department of Energy’s Shale Gas Production Subcommittee, testified to the U.S. Senate Committee on Energy and Natural Resources that the chemicals used in fracturing fluids are “relatively benign” and that steps are being taken to make them safer.103

Public suspicion about the chemical composition of fracturing fluids was exacerbated when some exploration and production companies and service companies initially refused to disclose the chemical makeup of their fracturing fluids—citing trade secret concerns. Given that public reaction, however, other companies began to voluntarily disclose the chemical composition of their fracturing fluids on a publicly available website: www.fracfocus.org. A number of states—including Arkansas, Colorado, Montana, Oklahoma, Pennsylvania, Texas and Wyoming—have now enacted laws or regulations requiring public disclosure of the chemical composition of fracturing fluids.

(c) Allegation That Hydraulic Fracturing Leads to Flammable Drinking Water

The movie “Gasland” first popularized the notion of flammable drinking water (with dramatic footage) in which a landowner in Colorado lit his drinking water on fire—and claimed that hydraulic fracturing had made it flammable.

The oil and gas industry’s typical response is that, long before hydraulic fracturing was used to stimulate oil and gas wells, it was known that under certain conditions methane—a natural hydrocarbon gas—can migrate into water wells.104 That methane migration can make drinking water flammable. Thus, there is no connection between hydraulic fracturing and methane gas in any home water supply.

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102 DOE Shale Primer, supra note 1, at p. 62.
103 To Receive Testimony on the Secretary of Energy Advisory Board’s Shale Gas Production Subcommittee’s 90-day Report Before the S. Comm. on Energy and Natural Resources, 112th Cong. (Oct. 4, 2011) (testimony of Mark Zoback, Professor of Geophysics, Stanford University, at p. 2).
Following the release of Gasland, regulators in Colorado issued a fact sheet seeking to “correct several errors” made in the film—including the one about flammable drinking water. After careful study, the Colorado regulators found that the well featured in Gasland “contained biogenic methane that is not attributable to [oil and gas] development.” Rather, “the water well completion report . . . shows that it penetrated at least four different coal beds. The occurrence of methane in the coals of the Laramie Formation has been well documented . . . .”

(d) Conclusion

Notwithstanding the foregoing, most critics of hydraulic fracturing would likely acknowledge—perhaps grudgingly—that hydraulic fracturing is critical to U.S. domestic hydrocarbon production and is, therefore, “here to stay.” Rather than advocating for a complete ban on hydraulic fracturing, most critics would prefer greater federal oversight and regulation of hydraulic fracturing—with the implicit assumption being that state regulators are incapable of overseeing and regulating it on their own. Several federal agencies are currently considering a variety of regulations directed at hydraulic fracturing. For example, in May 2012, the U.S. Department of Interior, Bureau of Land Management (“BLM”), issued proposed regulations that would govern hydraulic fracturing and well stimulation operations on federal and Indian lands. Among other things, the proposed regulations would require that, prior to commencement of well stimulation operations, the operator: (1) obtain BLM approval of the proposed well stimulation operations; (2) submit to the BLM a wide range of data related to geology and mechanical integrity of the well; and (3) disclose to the BLM the chemicals/additives proposed to be used in the well stimulation fluids.

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106 Id. at p. 1
107 Id. at p. 2.
IV. Water Management

After a hydraulic fracture treatment, when the pumping pressure has been relieved from the well, the water-based fracturing fluids begin to flow back through the well casing to the wellhead.109 This is commonly referred to as flow-back water.110 The majority of fracturing fluids are recovered in a matter of several hours to a couple of weeks.111 Produced water—which is water that has been trapped in the target formation—may also flow back through the well casing to the wellhead.112 Drilling operators often temporarily store flow-back and produced water in open-air, lined retention ponds at the well site.113 However, operators must reclaim the temporary storage pits when the drilling and fracturing operations end. And the operators must permanently dispose of the flow-back and produced water, which can present a considerable challenge.114

Underground injection is the preferred method of disposing of produced water.115 This process uses salt water disposal wells to place the water thousands of feet underground in porous rock formations that are separated from groundwater aquifers by multiple layers of impermeable rock thousands of feet thick.116 However, underground injection is not possible in every play as suitable injection zones may not be available nearby.117 An alternative is to transport the produced water to a more distant injection

109 DOE Shale Prime, supra note 1, at p. 66.
110 90-Day Report, supra note 21, at p. 21.
111 DOE Shale Prime, supra note 1, at p. 66.
112 90-Day Report, supra note 21, at p. 21.
113 CRS Shale Development, supra note 12, at p. 34.
114 See, e.g., DOE Shale Primer, supra note 1, at p. 66.
115 Id.
116 Id.
117 Id.
site. For example, in the Barnett Shale, pipelines have been constructed to transport such water to injection well disposal sites.

The most common use of flow-back water is to re-cycle/re-use it in subsequent hydraulic fracturing operations. In fact, in the Eagle Ford Shale and the Marcellus Shale operators are now recycling approximately 80% of their flow-back water. The industry’s preference for re-cycling/re-using flow-back water is easy to understand. Operators enjoy significant cost savings—by avoiding most of the costs associated with treating, transporting, and disposing of flow-back water—and reduce their overall fresh water use.

V. Concerns About Water Use

Water use can be an emotionally charged subject in many communities. The drilling and hydraulic fracturing of horizontal shale wells can require 2 to 4 million gallons of water, with about 3 million gallons being typical. Water for drilling and hydraulic fracturing of these wells frequently comes from surface water bodies such as rivers and lakes, but can also come from groundwater, private water sources, and municipal water. Given the drought conditions experienced over the past year in much of the southern United States, significant public concern has been expressed about hydraulic fracturing operations depleting water resources—particularly in Texas.

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118 Id.
119 Id.
120 CRS Shale Development, supra note 12, at p. 34-35.
121 See, e.g., Magnum Hunter Resources Corp., PRESENTATION TO THE SHALE GAS WATER MANAGEMENT 2011 CONFERENCE, at pgs. 11 & 17 (Nov. 2011) (on file with the author) [hereinafter Magnum Hunter Presentation].
122 Id.
123 DOE Shale Primer, supra note 1, at p.64. Although that volume may sound high, it is relatively insignificant when compared to overall water use in a given area. See, e.g., Dave Yoxtheimer, P.G., Water Sourcing Regulations for Marcellus Natural Gas Development in Pennsylvania, Presentation to the Shale Gas Water Management Initiative, at p. 3 (Dec. 1, 2011) (on file with the author) (of the 9.48 billion gallons of water used per day in Pennsylvania, hydraulic fracturing only uses 10 million gallons of water per day).
124 DOE Shale Primer, supra note 1, at p.64-65.
The oil and gas industry has attempted to counter those concerns by publicizing the fact that the average natural gas well contributes far more water to the hydrologic cycle than it uses.\textsuperscript{125} In the hydrologic cycle, evaporated water becomes part of nature’s recycling system and eventually returns to the earth as rain.\textsuperscript{126} Natural gas, like all fossil fuels, produces water when it is combusted.\textsuperscript{127} The oil and gas industry estimates that, for every 1 million cubic feet of natural gas that is burned, about 10,675 gallons of water are produced.\textsuperscript{128} Thus, a typical Barnett Shale natural gas well, producing 2 million cubic feet per day, creates more than 20,000 gallons of water daily.\textsuperscript{129} It takes just 250 days of production and combustion to replace the water used to drill and hydraulically fracture a Barnett Shale well.\textsuperscript{130}

The industry is also developing chemicals that allow hydraulic fracturing with brine and use of non-potable sources of water.\textsuperscript{131}

VI. Transporting Hydrocarbons From Wellhead to Market

There are basically two kinds of producing wells—oil wells and natural gas wells. The difference is largely determined by the relative quantities of liquid and vapor produced from the well. Oil wells, after initial separation, can produce crude oil and associated natural gas.\textsuperscript{132} Natural gas wells, after initial separation, can produce natural

\begin{itemize}
  \item \textsuperscript{125} See, e.g., Ed Ireland, Ph.D., \textit{Barnett Shale Energy Education Council}, Presentation to the Shale Gas Water Management Initiative, at p. 3 (Dec. 1, 2011) (on file with the author).
  \item \textsuperscript{126} Id.
  \item \textsuperscript{127} Id.
  \item \textsuperscript{128} Id.
  \item \textsuperscript{129} Id.
  \item \textsuperscript{130} Id.
  \item \textsuperscript{131} \textit{Magnum Hunter Presentation}, supra note 120, at p. 10.
  \item \textsuperscript{132} J.T. (Tom) Mitchell, \textit{From Extraction to End Use: the Marketing Background}, 2003-1 ROCKY MTN. MIN. L. INST. 2, at p. 1 (2003) [hereinafter \textit{Marketing Background}]. Natural gas found with crude oil is known as associated gas (or when produced is called casinghead gas). Kyle L. Pearson, \textit{From Extraction to End Use: The Technical Background}, 2003-1 ROCKY MTN. MIN. L. INST. 1, at p. 2 (2003) [hereinafter \textit{Technical Background}]. Where as, gas found separate from crude oil is called nonassociated gas. \textit{Id.}
gas and condensate. Different methods of transportation are used to move these hydrocarbons from wellhead to market.

A. **Crude Oil and Condensate**

Crude oil and condensate are liquids at normal conditions of temperature and pressure. Condensate is, in fact, simply a very light crude oil at the surface. Crude oil and condensate can both be stored at the lease in tanks and transported to refineries by truck, railcar, barge, ship, or pipeline. Refineries then process them into finished petroleum products such as gasoline, jet fuel, diesel fuel, heating oil, and heavy fuel oil.

B. **Natural Gas**

Natural gas is typically transported from wellhead to market through a series of pipelines. These pipelines can be either inter-state or intra-state pipelines. The natural gas fed into the pipeline system in the United States must meet specific quality measures for the pipeline grid to operate properly. As a result, natural gas produced at the wellhead—which can contain contaminants and natural gas liquids—must be processed (i.e., cleaned) before it can be safely delivered to the pipelines that transport the gas to the consuming public. The biggest contaminant is typically water vapor.

Gas is typically moved away from the wellhead through a gathering system. Gathering lines are small-diameter pipes that connect the wells in a producing area to

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133 Marketing Background, supra note 131, at p. 1.
134 Id.
135 Id.
136 Id.
137 Id. at p. 2.
138 Inter-state pipelines are regulated by the Federal Energy Regulatory Commission. Where as, intra-state pipelines are regulated by the State in which the pipeline is located.
139 Id. at p. 8; Marketing Background, supra note 131, at p. 6.
140 Moving the Molecules to Market, supra note 138, at p. 10; Karen Ostrander-Krug, A Natural Gas Primer, 34B ROCKY MNT. MIN. L. INST. 2, at p. 16 (1993) [Hereinafter NG Primer].
After the gas is gathered, it is usually compressed. Compression increases both the pressure and temperature of the natural gas and assists in the efficient transportation of the gas for distribution and consumption. Compression occurs at multiple locations between the wellhead and end use of natural gas, including at the well sites, within gathering systems, at centralized compressor stations, at natural gas processing plants, and within intra- and inter-state pipeline networks.

After natural gas is delivered to a processing plant through a gathering system, it is then processed. The processing of wellhead natural gas into pipeline-quality dry natural gas can be quite complex and usually involves several processes to remove: (1) oil; (2) water; (3) elements such as sulfur, helium, and carbon dioxide; and (4) natural gas liquids. The number of steps and the types of techniques used in the process of creating pipeline-quality natural gas most often depends upon the source and makeup of the wellhead production stream. Following processing, the processed natural gas is sent out of the processing plant via an output (tailgate) lateral that is interconnected to one or more major intra- and inter-state pipeline networks. Liquids removed at the processing plant usually will be taken away by pipeline to petrochemical plants, refineries, and other gas liquids customers. Some of the heavier liquids are often temporarily stored in tanks on site and then trucked to customers.

142 NG Primer, supra note 140, at p. 16.
143 Id.
144 See Technical Background, supra note 131, at p. 6.
145 Natural gas compressor stations, especially those located in production areas, may also serve as field level processing facilities. They often include additional facilities for dewatering natural gas and for removal of many hydrocarbon liquids.
146 See Technical Background, supra note 131, at p. 6.
147 Moving the Molecules to Market, supra note 138, at p. 10.
148 Id.
149 Id.
More than 500 natural gas processing plants currently operate in the United States. Most are located in proximity to the major natural gas/oil producing areas of the Southwest and the Rocky Mountain States.

VII. Well Abandonment and Site Restoration

When its useful life is over, a well must be prepared for abandonment. These procedures are normally known as plugging and abandonment (“P&A”). The objectives of P&A include protecting freshwater aquifers from contamination by formation fluid migration or surface water runoff, isolating productive or noncompleted producible hydrocarbon intervals, protecting surface soils and waters from contamination by formation fluid migration to the surface, and minimizing conflict with surface land use.

A site survey and closure plan can be a helpful tool in evaluating restoration requirements for a particular site. In general, a survey should include some or all of the following:

- A review of the site operating records and history.
- A review of facility and flow-line drawings and physical verification.
- Soil sampling for oil and grease, salt, and metals contamination.
- Reserve and production pit surveys and sampling.
- Other steps such as hydrocarbon inventory and identification of any hazardous wastes.

After compilation of a site survey, P&A is generally accomplished by removing the surface facilities, equipment, and casing down to a certain depth below the surface or mud line. The wellbore is also plugged by placing cement, metal plugs, or other

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150 Id. at p. 13.
151 Id.
152 Berry St. John & Craig Wyman, Restoration of Oil Field Sites Remediation Requirements for Major Oil and Gas Producing Jurisdictions, at p. 7 (1st ed. 1999).
153 Id.
154 Id.
materials in the wellbore at selected locations.\textsuperscript{155} Cementing operations are also used extensively in P&A activities to isolate formations further.\textsuperscript{156} An operator must conduct pressure and other testing to ensure the integrity of the P&A operations.

In addition to P&A obligations, an operator must remove related equipment and restore the surface. These tasks include closing any associated production pits and dismantling and removing any tank batteries, surface pipe, and other equipment from the well site.\textsuperscript{157} Typically, top soil is banked during site construction and subsequently returned to the reclaimed areas.\textsuperscript{158} Frequently, lease obligations also require grading the surface to restore natural contours.

A myriad of state and federal regulations govern site restoration. Failure to comply with such regulations can lead to an operator being subject to fines or other penalties and potential civil liability. State regulatory agencies will also hold an operator’s bond to ensure work gets done.

In addition to the specific P&A obligations imposed on operators, non-operating working interest owners are responsible for their proportionate share of the costs to plug and abandon a well.

\textbf{VIII. Conclusion}

Advances in horizontal drilling and hydraulic fracturing have unlocked vast hydrocarbon-rich shale resources for the United States. A long horizontal well increases the length of the wellbore in the hydrocarbon-bearing formation and therefore increases the surface area for hydrocarbons to flow into the wellbore. Moreover, horizontal drilling allows an area to be developed with substantially fewer wells than would be needed if vertical wells were used. Hydraulic fracturing, in turn, substantially increases the flow of hydrocarbons from low permeability (tight) shale formations by creating a network of interconnected fractures through which hydrocarbons can flow to the wellbore. While

\textsuperscript{155} Id.
\textsuperscript{156} Id.
\textsuperscript{157} Id.
\textsuperscript{158} Id.
challenges continue to exist with water availability and water management, innovative regional solutions are emerging that allow shale development to continue while ensuring that the water needs of other users can be met and that surface and ground water quality is protected.

As a result of the advances in horizontal drilling and hydraulic fracturing, the United States now has an ample supply of low cost natural gas, which is an environmentally friendly fuel. Moreover, the United States has dramatically increased its crude oil production, and thereby reduced its dependence on foreign oil. Some industry pundits have even predicted that the United States might be able to supply its own crude oil needs in the future, which would lead to enormous economic and national security benefits.