Environmental Impacts of Hydraulic Fracturing

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For

Nancy Lutje

Suzanne Wilson

Nobody realizes that some people expend tremendous energy merely to be normal.

—Albert Camus (1913–1960)

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Preface

With regard to gaining U.S. energy independence and a sustainable, reliable source of energy, the current push to develop renewable energy sources, including hydropower, wave and tidal power, geothermal energy, bioenergy, wind-derived power, solar energy, and fuel cell technology, makes good sense. Although there is considerable argument about which of these potential long-term energy sources is best to develop (i.e., holds the most promise), there can be little doubt as to the need for innovation and the development of viable renewable energy sources.

Just when many of us had decided that the United States was energy poor, that we are running out of hydrocarbon supplies or are lacking relatively easy access to potential hydrocarbon supplies, technology is advancing to the point where natural gas supplies recently thought to be nonexistent or too difficult to mine are now being discovered, mined, and processed and are now available for both industrial and consumer use. Not only is this important for future U.S. natural gas supplies but natural gas also plays a key role in our nation's pursuit of a clean energy future.

Technological development that has made access to newly discovered massive supplies of natural gas is not actually new technology; it has been around for years. Indeed, *hydraulic fracturing*, often called *fracking*, *fracing*, or *hydrofracking* (or even *well stimulation*, as many in the industry like to call it), is a well-known practice that was developed by Haliburton almost 60 years ago. The use of hydraulic fracturing is a double-edged sword, a Dr. Jekyll and Mr. Hyde operation (i.e., both a benefit and a liability). On the one side, the fracturing process, known as a *frack job*, involves the pressurized injection of fluids commonly made up of water and chemical additives into a geologic formation (e.g., gas-bearing shale). The pressure exceeds the rock strength, and the fluid opens or enlarges fractures in the rock. As the formation is fractured, a *propping agent*, such as ceramic or sand beads (even peanut and walnut shells have been used) is pumped into the fractures to keep them from closing as the pumping pressure is released. The fracturing fluids (water and chemical additives) are then returned back to the surface. Natural gas will flow from pores and fractures in the rock into the well for subsequent extraction.

Hydraulic fracturing has proven to be one viable way of accessing vital resources such as natural gas, oil, and geothermal energy. Simply, hydraulic fracturing has helped to expand natural gas production in the United States by unlocking large natural gas supplies in shale and other unconventional formations across the country. The results of hydraulic fracturing are startling. Natural gas production in 2010 reached the highest level in decades. According to the most recent estimates by the Energy Information Administration (EIA),* the United States possesses natural gas resources sufficient to supply the country for more than 110 years. Moreover, the technology has also been used successfully to stimulate water wells, whereby the fluid used is usually pure water (typically water and a chlorine-based disinfectant, such as bleach). Hydraulic fracturing has also been used to remediate waste spills by injecting air, bacteria, or other materials into a subsurface contaminated zone.

On the other edge of the fracking double-edged sword—in line with the old adage that anything that has a good side probably has a few negative aspects lingering in the background or in the bushes somewhere—hydraulic fracturing certainly has its critics, who point out that the process is not exactly a bed of beautiful roses. As the use of hydraulic fracturing has grown, so have concerns about its environmental and public health impacts; for example, a 2011 U.S. House of Representatives Committee Report† observed that hydraulic fracturing raises myriad concerns, including risks to air quality, migration of gases and hydraulic fracturing chemicals to the surface, potential mishandling of wastes (especially wastewaters), land subsidence, and, most importantly, the contamination of ground water. Of these varied concerns the most significant to date is the hydraulic fracturing fluids used to fracture rock formations. These contain numerous chemicals that could harm human health and the environment, especially if they enter and contaminate drinking water supplies. Compounding the concerns of Congress, local politicians, and environmentalists is the resistance of many oil and gas companies to publicly disclosing the chemicals they use.

Environmental Impact of Hydraulic Fracturing provides a fair and balanced discussion and comprehensive guide to every aspect of the process of hydraulic fracturing used to extract natural gas, along with gas exploration and production in various shale fields. The book provides comprehensive coverage of all aspects of the issue, including ongoing controversies about the environmental and operator safety issues arising from possible water pollution, drinking water contamination, on-the-job safety hazards, and harmful chemical exposure to workers and residents near well areas. Several case studies on the fracking process and its ramifications are provided. This book is intended as a reference book for administrators; legal professionals; research engineers; graduate students in chemical, natural gas, petroleum, or mechanical engineering; non-engineering professionals; and the general reader.

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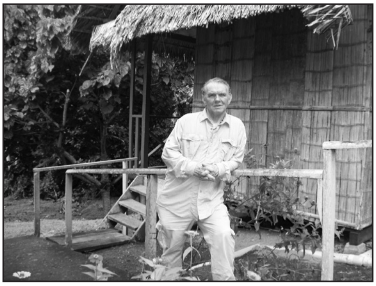
* EIA, *U.S. Natural Gas Monthly Supply and Disposition Balance*, U.S. Energy Information Administration, Washington, DC, 2012 (online at (http://www.eia.gov/dnav/ng/ng_sum_sndm_s1_m.htm).

† USHR, *Chemicals Used in Hydraulic Fracturing*, Committee on Energy and Commerce, U.S. House of Representatives, Washington, DC, 2011.

Author



Frank R. Spellman, PhD, is a retired U.S. Naval Officer with 26 years of active duty, a retired environmental safety and health manager for a large wastewater sanitation district in Virginia, and a retired assistant professor of environmental health at Old Dominion University, Norfolk, Virginia. He is the author or co-author of 75 books, with more soon to be published. Dr. Spellman consults on environmental matters with the U.S. Department of Justice and various law firms and environmental entities around the globe. He holds a BA in public administration, BS in business management, and MBA, MS, and PhD in environmental engineering. In 2011, he traced and documented the ancient water distribution system at Machu Pichu, Peru, and surveyed several drinking water resources in Amazonia, Ecuador.

Acronyms and Abbreviations

API	American Petroleum Institute
bbl	Barrel, petroleum (42 gallons)
bcf	Billion cubic feet
BLM	Bureau of Land Management
BMP	Best Management Practices
Btu	British thermal unit
CAA	Clean Air Act
CBNG	Coal bed natural gas
CEQ	Council on Environmental Quality
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
COE	Coefficient of oil extraction
CWA	Clean Water Act
DRBC	Delaware River Basin Commission
EIA	Energy Information Administration
ELG	Effluent Limitation Guidelines
EPA	Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
FR	*Federal Register*
ft	Foot/feet
FWS	Fish and Wildlife Service
gal	Gallon
GHG	Greenhouse gases
GWPC	Ground Water Protection Council
H_2S	Hydrogen Sulfide
HAP	Hazardous Air Pollutant
HCl	Hydrochloric acid
IOGCC	Interstate Oil and Gas Compact Commission
IR	Infrared
Mcf	1000 cubic feet
MMcf	1,000,000 cubic feet
mrem	Millirem
mrem/yr	Millirem per year
MSDS	Material Safety Data Sheet
NEPA	National Environmental Policy Act
NESHAPS	National Emission Standards for Hazardous Air Pollutants

NETL	National Energy Technology Laboratory
NORM	Naturally occurring radioactive material
NO_x	Nitrogen oxides
NPDES	National Pollution Discharge Elimination System
NYDEC	New York State Department of Environmental Conservation
O_3	Ozone
OPA	Oil Pollution Act
OSHA	Occupational Safety and Health Administration
PM	Particulate matter
ppm	Parts per million
RAPPS	Reasonable and Prudent Practices for Stabilization
RCRA	Resource Conservation and Recovery Act
RP	Recommended Practice
RQ	Reportable quantity
SARA	Superfund Amendments and Reauthorization Act
SCF	Standard cubic feet
SDWA	Safe Drinking Water Act
SO_2	Sulfur dioxide
SPCC	Spill Prevention, Control, and Countermeasures
SRBC	Susquehanna River Basin Commission
STRONGER	State Review of Oil and Natural Gas Environmental Regulations, Inc.
SWDA	Solid Waste Disposal Act
tcf	Trillion cubic feet
TDS	Total dissolved solids
tpy	Tons per year
TRI	Toxic Release Inventory
UIC	Underground Injection Control
USC	United States Code
USDW	Underground source of drinking water
USGS	United States Geological Survey
VOC	Volatile organic compound
WQA	Water Quality Act
yr	Year

1

Introduction

There is nothing new about splitting or cracking rocks to release substances that mankind needs or desires. Consider, for example:

> He split the rocks in the wilderness,
> And gave them drink abundantly as out of the depths.
> He brought streams also out of the rock,
> And caused waters to run down like rivers.
>
> **—Psalm 78:15–18 (World English translation)**

1.1 Shalenanza

Most of us are familiar with the term *bonanza*, which refers to something that is very valuable, profitable, or rewarding. Moreover, many of us have an even more tangible or palatable feeling for the meaning of the glittery term—specifically, those who have witnessed, studied, or experienced a rags-to-riches metamorphosis, whereby they themselves or people they know have been impacted by the discovery of exceptionally large and rich mineral deposits of, for example, ores, precious metals, petroleum, or natural gas.

On the other hand, readers who have noticed the title of this section are scratching their heads and wondering … shale what? Well, I can't say that I am surprised because I just invented the term, so bear with me as I explain what *shalenanza* means. First of all, suppose that you reside in a hard-luck, high-unemployment town such as Youngstown, Ohio, and a new industrial plant is being built that will employ hundreds. This new plant will produce seamless steel pipes for tapping shale formations for oil or natural gas. Thus, a rust belt town with over 11% unemployment will now have at least 450 new jobs. The source of Youngstown's new-found good luck is the vast stores of natural gas in the Marcellus and Utica shale formations that have set off a modern shale gas rush to grab leases and secure permits to drill. The Marcellus boom could offer large numbers of jobs for more than 50 years.

Now, the obvious question: Is the economic windfall enjoyed by Youngstown unique to that area only? The simple and compound answer to this question is no. Similar hopes are alive for other hard-luck towns in Ohio, Pennsylvania, West Virginia, New York, Kentucky, Tennessee, and Alabama. Consider, for example, Lorain, Ohio, where U.S. Steel will add 100 jobs with a $100 million upgrade of a plant that makes seamless pipe for construction or gas exploration and production industries (Sheeran, 2011). Also, in Pittsburgh, U.S. Steel will eventually add a significant number of jobs with construction of a multibillion dollar petrochemical refinery; Ohio had been in the running for the plant. The refinery will convert natural gas liquids to other chemicals used in heating fuel, power generation, transportation fuel, plastics, tires, fabrics, glass, paint, and antifreeze (Anon., 2012). Beneficiaries of shale development and the manufacture of ancillary equipment also include railcar industries; the shale industry has caused an increased need for freight cars, and at present producers of such rail cars have a backlog of orders.

What we have here is a modern-day gold rush or, more correctly, a shale gas rush, which I have termed a *shalenanza*, which has created many *shaleionaires* (a term invented by someone else). Simply, in a tough economy, when families are struggling to make ends meet and business owners are facing declining revenues and tough choices, the windfall generated by and garnered from this *shalenanza* can only be characterized as an economic blessing. One group of folks who know exactly what I am referring to here and who know the exact meaning of the term *shalenanza* are those poor dirt farmers in the hill country of western Pennsylvania. These are folks who have been working hard to eke out a living from the land while at the same time drawing unemployment compensation and food stamps because of lost manufacturing jobs in a depressed economic region. Investors and speculators knocking down their doors to have them sign lucrative leases to the mineral rights on their property is a morale booster that might leave most landowners speechless, scratching their brains cells for the right words to say. May I suggest one word: *shalenanza*?

1.2 Other Side of the Coin

(*Note:* Many of the issues discussed in this section are presented only briefly here but are developed to a greater extent later in the text.) Like many bonanzas or gold rushes in the past, the shale gas shalenanza or rush has made a few people rich and others desperate or downright miserable. The problem? Take your pick. A few landowners in shale-rich areas have received thousands of dollars an acre in upfront payments (with the promise of thousands more to come in royalties) for the right to drill under their property. These folks are the so-called shaleionaires.

At the same time, some of their neighbors—many of whom are also shaleionaires—have drawn water from their taps that can only be characterized as brown, smelly, and, on occasion, explosive. Because shale gas is imbedded in dense, low-permeability rock, drillers use a mixture of water, sand, ceramic beads, peanut shells, and chemicals to open up fissures in the stone through which the gas can escape up. This, of course, is the process that this text is concerned with—*hydraulic fracking* or, more colloquially, *fracking* or *fracing*. Critics of fracking have pointed the finger of blame for contaminated tapwater (and other environmental issues) at former Vice President Dick Cheney, who largely authored the 2005 Energy Bill (the so-called Halliburton Loophole), which explicitly exempted fracking from federal review under the Safe Drinking Water Act (SDWA). Under this provision, drilling companies are under no obligation to make public which chemicals they use, although many of them are recognized or suspected carcinogens. The U.S. Environmental Protection Agency (USEPA) is currently investigating cases of suspected contamination in towns located near fracking activities.

Beyond contaminated tapwater, other issues of concern are related to environmental contamination of water, air, and the land. With regard to tapwater and other water contamination events related to shale natural gas extraction, the primary concerns are threefold: (1) contamination of surface water due to erosion and groundcover removal during drilling site extraction; (2) proper management of separate but multiple users in a single watershed to protect water quality and ensure adequate water resources to meet the needs of the watershed stakeholders; and (3) treatment and safe disposal of the water produced.

With regard to air quality, natural gas is often lauded as the cleanest of all fossil fuels, and its air quality benefits are rarely disputed; however, it is the *production* of natural gas that is the problem. Its extraction from shale impacts air quality and releases greenhouse gases into the atmosphere. The impact of these air emissions released during drilling and production varies, depending on the phase of the drilling operation. And then there is a potential air emission problem when drilling and fracking are completed, production begins, and permanent emission sources are established (e.g., compressor engines, venting or leaking condensate tanks, collection ponds). Fluids brought to the surface can include a mixture of natural gas, water, and hydrocarbon liquids—the greater the amount of water and hydrocarbon liquids, the "wetter" the gas. Wet gas must be dehydrated to separate the gases from the water and hydrocarbons, resulting in the production of a *condensate*. Hydrocarbons can be released from the condensate whenever it is stored and transported from the site to refineries for incorporation into liquid fuels. In addition, fugitive and intermittent emissions from equipment and transmissions also occur.

The surrounding drilling and hydraulic fracturing land area can also be subject to contamination. Specifically, surrounding farmland and forests near the wellhead can be severely impacted not only by drilling and fracking activities but also by the movement of heavy drilling and fracking equipment over the land areas, causing soil compaction (League of Women Voters, 2009). Another recent issue with hydraulic fracking for oil and natural gas is earthquakes. Some are beginning to question whether the magnitude

5.6 earthquake that rocked Oklahoma on November 5, 2011, was caused by fracking. The following section provides a basic understanding of earthquakes and their causes.

1.3 Earthquakes

> *It's been raining a lot, or very hot—it must be earthquake weather!*
> *FICTION:* Many people believe that earthquakes are more common in certain kinds of weather. In fact, no correlation with weather has been found. Earthquakes begin many kilometers (miles) below the region affected by surface weather. People tend to notice earthquakes that fit the pattern and forget the ones that don't. Also, every region of the world has a story about earthquake weather, but the type of weather is whatever they had for their most memorable earthquake.
>
> **—USGS (2009)**

1.3.1 What Causes Earthquakes?

Anyone who has witnessed or studied one of the over a million or so earthquakes that occur each year on Earth is unlikely to forget such occurrences. Even though most earthquakes are insignificant, a few thousand of them produce noticeable effects such as tremors and ground shaking. The passage of time has shown that about 20 earthquakes each year cause major damage and destruction. It is estimated that about 10,000 people die each year because of earthquakes. Over the millennia, the effects of damaging earthquakes have been obvious to those who witness the results; however, the cause of earthquakes has not been as obvious. The cause of earthquakes has shifted from being the wrath of mythical beasts to the wrath of gods, from being unexplainable magical occurrences to normal, natural phenomena occasionally required to retain Earth's structural integrity. We can say, overall, that an earthquake on Earth provides our planet with a sort of a geological homeostasis required to maintain life as we know it. Through the ages earthquakes have come under the scrutiny of some of the world's greatest writers. Consider, for example, Voltaire's classic satirical novel, *Candide*, published in 1759, in which he mercilessly satirizes science and, in particular, earthquakes. Voltaire based his observations on the great Lisbon, Portugal, earthquake that occurred in 1759 and caused the deaths of more than 60,000 people. Upon viewing the total devastation of Lisbon, Dr. Pangloss says to Candide:

> … the heirs of the dead will benefit financially; the building trade will enjoy a boom. Private misfortune must not be overrated. These poor people in their death agonies, and the worms about to devour them, are playing their proper and appointed part in God's master plan.

Although we still do not know what we do not know about earthquakes and their causes, we have evolved from using witchcraft or magic to explain their origins to the scientific methods employed today. In the first place, we do know that earthquakes are caused by the sudden release of energy along a fault. Earthquakes are usually followed by a series of smaller earthquakes that we refer to as *aftershocks*. Aftershocks represent further adjustments of rock along the fault. There are currently no reliable methods for predicting when earthquakes will occur.

We have developed a couple of theories with regard to the origin of earthquakes. One of these theories suggests that earthquakes occur via *elastic rebound*. According to the elastic rebound theory, subsurface rock masses subjected to prolonged pressures from different directions will slowly bend and change shape. Continued pressure sets up strains so great that the rocks will eventually reach their elastic limit and rupture (break), suddenly snapping back into their original unstrained state. It is the snapping back (elastic rebound) that generates the seismic waves radiating outward from the break. The greater the stored energy (strain), the greater the release of energy. The coincidence of many active volcanic belts with major belts of earthquake activity indicates that volcanoes and earthquakes may have a common cause. Plate interactions commonly cause both earthquakes (tectonic earthquakes) and volcanoes.

1.3.2 Seismology

Seismology is generally considered to be the study of earthquakes, but it is actually the study of how seismic waves behave in the Earth. The source of an earthquake is the *hypocenter* or *focus* (i.e., the exact location within the Earth where seismic waves are generated). The *epicenter* is the point on the Earth's surface directly above the focus. Seismologists want to know where the focus and epicenter are located so a comparative study of the behavior of the earthquake event can be made with previous events to further our understanding of earthquakes. Seismologists use instruments to detect, measure, and record seismic waves. Generally, the instrument used is the *seismograph*, which has been around for a long time. Modern improvements have upgraded these instruments from paper or magnetic tape strips to electronically recorded digital data. The relative arrival times of the various types of waves at a single location can be used to determine the distance to the epicenter. To determine the exact epicenter location, records from at least three widely separated seismograph stations are required.

1.3.2.1 Seismic Waves

Some of the energy released by an earthquake travels through the Earth. The speed of these seismic waves depends on the density and elasticity of the materials through which they travel. Seismic waves come in several types:

- *P-waves*—Primary, pressure, or push–pull waves arrive first and are the first waves to be detected by a seismograph. They are compressional waves that expand and contract to travel through solids, liquids, or gases at speeds varying from 3.4 to 8.6 miles per second. P-waves move faster at depth, depending on the elastic properties of the rock through which they travel. P-waves are the same thing as sound waves.
- *S-waves*—Secondary or shear waves travel at a velocity between 2.2 and 4.5 miles per second, depending on the rigidity and density of the material through which they travel. They are the second set of waves to arrive at the seismograph and will not travel through gases or liquids; thus, the velocity of S-waves through gases or liquids is zero.
- *Surface waves*—Several types of surface waves travel along the Earth's outer layer or on layer boundaries within the Earth. These rolling, shaking waves are the slowest waves but the ones that cause damage in large earthquakes.

1.3.3 Earthquake Magnitude and Intensity

The size of an earthquake is measured using two parameters—energy released (*magnitude*) and damage caused (*intensity*).

1.3.3.1 Earthquake Magnitude

The size of an earthquake is usually given in terms of its *Richter magnitude*, which was devised by Charles Richter. The Richter magnitude measures the amplitude (height) of the largest recorded wave at a specific distance from the earthquake. A better measure is the *Richter scale*, which measures the total amount of energy released by an earthquake as recorded by seismographs. The amount of energy released is related to the Richter scale by the equation:

$$\text{Log } E = 11.8 + 1.5M$$

where

Log = logarithm to base 10

E = energy released (in ergs)

M = Richter magnitude

When using the equation to calculate the Richter magnitude, it quickly becomes apparent that each increase of 1 in the Richter magnitude yields a 31-fold increase in the amount of energy released. Thus, a magnitude 6 earthquake releases 31 times more energy than a magnitude 5 earthquake. A magnitude 9 earthquake releases 31 × 31 or 961 times more energy than a magnitude 7 earthquake.

TABLE 1.1
Modified Mercalli Intensity Scale

Intensity	Description
I	Not felt except under unusual conditions
II	Felt by only a few on upper floors
III	Felt by people lying down or seated
IV	Felt by many indoors, by few outside
V	Felt by everyone, people awakened
VI	Trees sway, bells ring, some objects fall
VII	Causes alarm, walls and plaster crack
VIII	Chimneys collapse, poorly constructed buildings are seriously damaged
IX	Some houses collapse, pipes break
X	Ground cracks, most buildings collapse
XI	Few buildings survive, bridges collapse
XII	Total destruction

1.3.3.2 Earthquake Intensity

Earthquake intensity is a rough measure of an earthquake's destructive power—that is, its size and strength, or how much the Earth shook at a given place near the source of an earthquake. To measure earthquake intensity, Mercalli in 1902 devised an intensity scale of earthquakes based on the impressions of people involved, movement of furniture and other objects, and damage to buildings. The shock is most intense at the epicenter, which, as noted earlier, is located on the surface directly above the focus. Mercalli's intensity scale uses a series of numbers (on a scale of 1 to 12) to indicate different degrees of intensity (see Table 1.1). Keep in mind that this scale is somewhat subjective, but it provides both a qualitative and systematic evaluation of earthquake damage.

DID YOU KNOW?

Although it is correct to say that for each increase of 1 in Richter magnitude, there is a tenfold increase in amplitude of the wave, it is incorrect to say that each increase of 1 in Richter magnitude represents a tenfold increase in the size of the earthquake.

1.4 Internal Structure of Earth

Information obtained from seismographs and other instruments indicate that the lithosphere may be divided into three zones: crust, mantle, and core (see Figure 1.1):

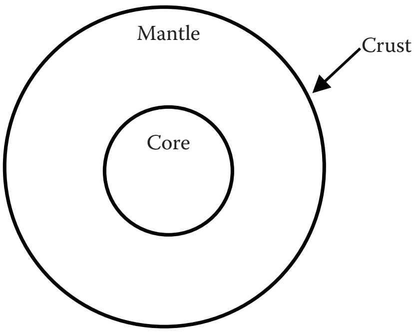


FIGURE 1.1
Internal structure of Earth.

- *Earth's crust*—The outmost and thinnest layer of the lithosphere is the crust. There are two different types of crust: (1) thin (as little as 4 miles in places) oceanic crust composed primarily of basalt that underlies the ocean basins, and (2) thicker continental crust (primarily granite 20 to 30 miles thick) that underlies the continents.
- *Earth's mantle*—Beneath the crust is an 1800-mile-thick intermediate, dense, hot zone of semisolid rock known as the mantle, which is thought to be composed mainly of olivine-rich rock.
- *Earth's core*—Earth's core is about 4300 miles in diameter. It is thought to be composed of a very hot, dense iron and nickel alloy. The core is divided into two different zones. The outer core is a liquid because the temperatures there are adequate to melt the iron–nickel alloy. The highly pressurized inner is core solid because the atoms are tightly crowded together.

As shown in the box on the next page, the controversy over whether earthquakes are generated because of wastewater injection and other fracking practices is bound to continue for some time. At present, most experts, including this author, are of the mind that the jury is still out. Scientists do not like to live by conjecture alone. There may be some truth to the earthquake fracking wastewater injection process, but the correlation has yet to be proven.

1.5 Key Definitions

Every branch of science, every profession, and every engineering process has its own language for communication. Hydraulic fracturing and shale-oil mining are no different. To work even at the edge of oil-shale fracking, you must acquire a fundamental vocabulary for the processes involved.

DID YOU KNOW?

In December 2011, the Associated Press reported that several officials believed that the 4.0 earthquake that struck northeast Ohio, outside Youngstown, was the 11th in a series of minor earthquakes in the area, many of which struck near the Youngstown injection well. Environmentalists and property owners living near the gas drilling well have questioned the safety of fracking to the environmental and public health. Federal regulators, however, have declared the technology safe. On January 1, 2012, an official in Ohio said that the underground disposal of wastewater from natural gas drilling operations would be halted in the Youngstown area until scientists could analyze data from the most recent string of earthquakes there (Fountain, 2012).

As Voltaire said, "If you wish to converse with me, define your terms." In this section, we define the terms and concepts used by fracking practitioners in applying their skills to make their technological endeavors bear fruit. These terms and concepts are presented early in the text so readers can become familiar with them now, before the text addresses the issues these terms describe. The practicing fracking engineer or student of fracking should understand these terms and concepts; otherwise, it will be difficult (if not impossible) to practice or understand fracking.

Hydraulic fracturing and shale gas drilling have an extensive and unique terminology that is generally well defined, but a few terms are not only poorly defined but also defined from different and conflicting points of view. Anytime we look to a definition for meaning, we are wise to remember the words of Voltaire, as well as those of another great philosopher, Yogi Berra, who defined things in his own unique way—for example, "95% of baseball is pitching, the other 50% is hitting."

1.5.1 Fracking Terminology

- *Air quality*—A measure of the amount of pollutants emitted into the atmosphere and the dispersion potential of an area to dilute those pollutants.
- *Aquifer*—A body of rock that is sufficiently permeable to conduct groundwater and to yield economically significant quantities of water to wells and springs.
- *Basin*—A closed geologic structure in which the beds dip toward a center location; the youngest rocks are at the center of a basin and are partly or completely ringed by progressively older rocks.
- *Bcf*—Billion cubic feet, a gas measurement equal to 1,000,000,000 cubic feet.

- *Biogenic gas*—Natural gas produced by living organisms or biological processes.
- *Btu*—British thermal unit, the amount of energy required to heat 1 pound of water by 1°F.
- *Casing*—Steel piping positioned in a wellbore and cemented in place to prevent the soil or rock from caving in. It also serves to isolate fluids, such as water, gas, and oil, from the surrounding geologic formations.
- *Coal bed methane (CBM)/coal bed methane gas (CBMG)*—A clean-burning natural gas found deep inside and around coal seams. The gas has an affinity to coal and is held in place by pressure from groundwater. CBMG is produced by drilling a wellbore into the coal seams, pumping out large volumes of groundwater to reduce the hydrostatic pressure, and allowing the gas to dissociate from the coal and flow to the surface.
- *Completion*—The activities and methods required to prepare a well for production following drilling, including installation of equipment for production from a gas well.
- *Corridor*—A strip of land through which one or more existing or potential utilities may be co-located.
- *Directional drilling*—The technique of drilling at an angle from a surface location to reach a target formation not located directly underneath the well pad.
- *Disposal well*—A well that injects produced water into an underground formation for disposal.
- *Drill rig*—The mast, draw works, and attendant surface equipment of a drilling or workover unit.
- *Emission*—Air pollution discharge into the atmosphere, usually specified by mass per unit time.
- *Endangered species*—Those species of plants or animals classified by the Secretary of the Interior or the Secretary of Commerce as endangered pursuant to Section 4 of the Endangered Species Act of 1973, as amended.
- *Exploration*—The process of identifying a potential subsurface geologic target formation and the active drilling of a borehole designed to assess the natural gas or oil.
- *Flow line*—A small-diameter pipeline that generally connects a well to the initial processing facility.
- *Formation (geologic)*—A rock body distinguishable from other rock bodies and useful for mapping or description. Formations may be combined into groups or subdivided into members.

- *Fracturing fluids*—A mixture of water and additives used to hydraulically induce cracks in the target formation.

DID YOU KNOW?

One well can be fracked 10 or more times, and there can be up to 30 wells on one pad. An estimated 50 to 60% of the fracking fluid is returned to the surface during well completion and subsequent production, bringing with it toxics gases, liquids, and solid material that are naturally present in underground gas deposits. Under some circumstances, none of the injection fluid is recovered (B.C. Oil & Gas Commission, 2001).

- *Flowback*—The fracture fluids that return to the surface after a hydraulic fracture is completed.
- *Frac*—Hydraulic fracturing, as adapted by the petroleum industry.
- *Groundwater*—Subsurface water that is in the zone of saturation and is the source of water for wells, seepage, and springs. The top surface of the groundwater is the *water table*.
- *Habitat*—The area in which a particular species lives. In wildlife management, the major elements of a habitat are considered to the food, water, cover, breeding space, and living space.
- *Horizontal drilling*—A drilling procedure in which the wellbore is drilled vertically to a kick-off depth above the target formation and then angled through a wide 90-degree arc such that the producing portion of the well extends horizontally through the target formation.
- *Hydraulic fracturing*—Injecting fracturing fluids into the target formation at a force exceeding the parting pressure of the rock, thus inducing a network of fractures through which oil or natural gas can flow to the wellbore.
- *Hydrostatic pressure*—The pressure exerted by a fluid at rest due to its inherent physical properties and the amount of pressure being exerted on it from outside forces.
- *Injection well*—A well used to inject fluids into an underground formation for either enhanced recovery or disposal.
- *Lease*—A legal document that conveys to an operator the right to drill for oil and gas. Also, the tract of land on which a lease has been obtained and where producing wells and production equipment are located.
- *Mcf*—A natural gas measurement unit for 1000 cubic feet.
- *MMcf*—A natural gas measurement unit for 1,000,000 cubic feet.

DID YOU KNOW?

Natural gas is generally priced and sold in units of 1000 cubic feet (Mcf, using the Roman numeral for one thousand). Units of a trillion cubic feet (Tcf) are often used to measure large quantities, as in resources or reserves in the ground or annual nation energy consumption. A Tcf is equal to 1 billion Mcf and is enough natural gas to

- Heat 15 million homes for one year
- Generate 100 billion kilowatt-hours of electricity
- Fuel 12 million natural gas-fired vehicles for one year

- *NORM*—Naturally occurring radioactive materials; includes naturally occurring uranium-235 and daughter products such as radium and radon.
- *Oil-equivalent gas (OEG)*—The volume of natural gas needed to generate the equivalent amount of heat as a barrel of crude oil. Approximately 6000 cubic feet of natural gas are equivalent to one barrel of crude oil.
- *Particulate matter (PM)*—A small particle of solid or liquid matter (e.g., soot, dust, mist). PM_{10} refers to particulate matter having a size diameter of less than 10 millionths of a meter (micrometer, or µm); $PM_{2.5}$ is less than 2.5 µm in diameter.
- *Permeability/porosity*—The capacity of a rock to transmit a fluid, which depends on the size and shape of pores and interconnecting pore throats. A rock may have significant porosity (many microscopic pores) but have low permeability if the pores are not interconnected (see Figures 1.2 to 1.5). Permeability may also exist or be enhanced through fractures that connect the pores. Though shales may be as porous as other sedimentary rocks, their extremely small pore sizes make them relatively impermeable to gas flow, unless natural or artificial fractures occur. Porosity is the percent volume of the rock that is not occupied by solids. Again, permeability is a measure of the ease with which a fluid can flow through a rock; the greater the permeability of a rock, the easier it is for the fluid to flow through the rock. Permeability is measured in units of *darcies* (D) or *millidarcies* (mD). A darcy is the permeability that will allow a flow of 1 cubic centimeter per second of a fluid with 1 centipoise viscosity (resistance to flow) through a distance of 1 centimeter through an area of 1 square centimeter under a differential pressure of 1 atmosphere (atm). In naturally occurring materials, permeability values range over many orders of magnitude.

DID YOU KNOW?

In 1850, Henri Darcy, the City Water Engineer for Dijon, France, received endless complaints about the filthy water coming from the city mains. Darcy installed sand filters to purify the system. While purifying water in the mains, Darcy experimented with fluid flow through porous materials and developed equations to describe it. For his efforts, Darcy earned immortality via the universally used *darcy*, a unit representing how easily fluid flows through porous media.

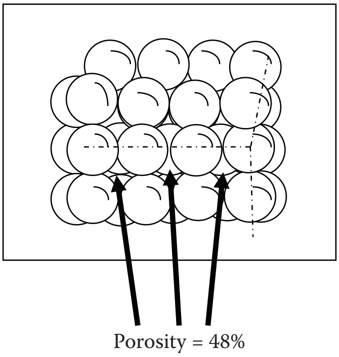


FIGURE 1.2
When spheres are stacked within a box, the empty space between the spheres equals 48% of the total volume. (Adapted from Raymond, M.D. and Leffler, W.L., *Oil and Gas Production in Nontechnical Language*, PennWell Corporation, Tulsa, OK, 2006.)

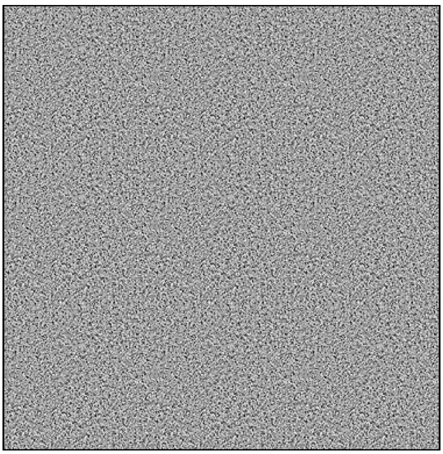


FIGURE 1.3
Well-sorted sand grains. (Adapted from Raymond, M.D. and Leffler, W.L., *Oil and Gas Production in Nontechnical Language*, PennWell Corporation, Tulsa, OK, 2006.)

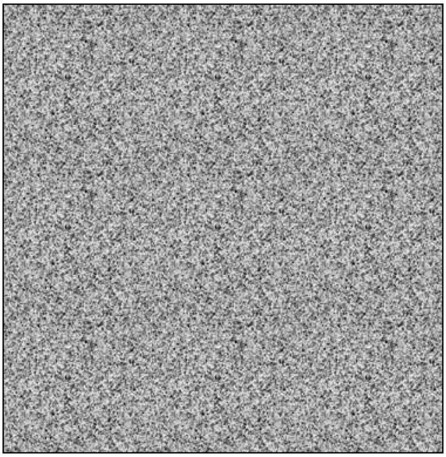


FIGURE 1.4
Poorly sorted sand grains. (Adapted from Raymond, M.D. and Leffler, W.L., *Oil and Gas Production in Nontechnical Language*, PennWell Corporation, Tulsa, OK, 2006.)

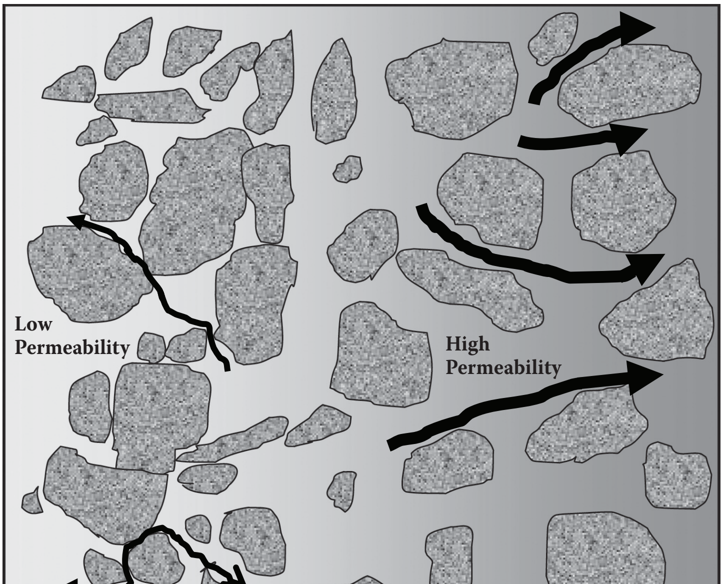


FIGURE 1.5
High- and low-permeability rock. (Adapted from Raymond, M.D. and Leffler, W.L., *Oil and Gas Production in Nontechnical Language*, PennWell Corporation, Tulsa, OK, 2006.)

- *Primacy*—A right that can be granted to states by the federal government that allows state agencies to implement programs with federal oversight. Usually, the states develop their own set of regulations. By statute, states may adopt their own standards; however, these must be at least as protective as the federal standards they replace and may be even more protective in order to address local conditions. Once these state programs are approved by the relevant federal agency (usually the USEPA), the state then has primary jurisdiction.
- *Produced water*—Water produced from oil and gas wells.
- *Propping agents/proppant*—Silica sand or other particles pumped into a formation during a hydraulic fracturing operation to keep fractures open and maintain permeability.
- *Proved reserves*—That portion of recoverable resources that is demonstrated by actual production or conclusive formation tests to be technically, economically, and legally producible under existing economic and operating conditions.
- *Reclamation*—Rehabilitation of a disturbed area to make it acceptable for designated uses. This normally involves regrading, replacement of topsoil, revegetation, and other work necessary to restore the area.
- *Setback*—The distance that must be maintained between a well or other specified equipment and any protected structure or feature.
- *Shale gas*—Natural gas produced from low-permeability shale formations.
- *Slickwater*—Water-based fracturing fluid mixed with a friction-reducing agent, commonly potassium chloride.
- *Split estate*—Condition that exists when the surface rights and mineral rights of a given area are owned by different persons or entities; also referred to as *severed estate*.
- *Stimulation*—Any of several processes used to enhance near-wellbore permeability and reservoir permeability.
- *Stipulation*—A condition or requirement attached to a lease or contract, usually dealing with protection of the environment or recovery of a mineral.
- *Sulfur dioxide* (SO_2)—A colorless gas formed when sulfur oxidizes, often as a result of burning trace amounts of sulfur in fossil fuels.
- *Tcf*—A natural gas measurement unit for one trillion cubic feet.
- *Technically recoverable resources*—The total amount of resources, discovered and undiscovered, thought to be recoverable with available technology, regardless of economics.

- *Thermogenic gas*—Natural gas that is formed by the combined forces of high pressure and temperature (both from deep burial within the Earth's crust), resulting in the natural cracking of the organic matter in the source rock matrix.
- *Thixotrophy*—The property of a gel to become fluid when disturbed (as by shaking).
- *Threatened and endangered species*—Plant or animal species that have been designated as being in danger of extinction.
- *Tight gas*—Natural gas trapped in a hardrock, sandstone, or limestone formation that is relatively impermeable.
- *Tight sand*—A very low or no permeability sandstone or carbonate.
- *Total dissolved solids (TDS)*—The dry weight of dissolved material, organic and inorganic, contained in water and usually expressed in parts per million.
- *Underground Injection Control (UIC) program*—A program administered by the USEPA, primacy state, or Indian tribe under the Safe Drinking Water Act to ensure that subsurface emplacement of fluids does not endanger underground sources of drinking water.
- *Underground source of drinking water (USDW)*—As defined by 40 CFR §144.3, a USDW is an aquifer or its portion:

  (a) (1) Which supplies any public water system; or

  (2) Which contains a sufficient quantity of groundwater to supply a public water system; and

  (i) Currently supplies drinking water for human consumption; or

  (ii) Contains fewer than 10,000 mg/L total dissolved solids; and

  (b) Which is not an exempted aquifer.
- *Water quality*—The chemical, physical, and biological characteristics of water with respect to its suitability for a particular use.
- *Watershed*—All lands that are enclosed by a continuous hydrologic drainage divide and lay upslope from a specified point on a stream.
- *Whipstock*—A wedge-shaped piece of metal placed downhole to deflect the drill bit.
- *Workover*—To perform one or more remedial operations on a producing or injection well to increase production. Deepening, plugging back, pulling, and resetting the line are examples of worker operations.

1.6 Purpose of Text

Although the title of this book, *Environmental Impacts of Hydraulic Fracturing,* makes clear the intention of the author to discuss hydraulic fracturing along with its impact on the environment, it is important to point out that it is not an attack on hydraulic fracturing or on the mining of natural gas, oil, or natural resources. Moreover, it is not an attack on our ongoing attempt to find and produce our own energy resources necessary to make the United States energy independent, maintain (at the minimum) our present living standards, and ensure their sustainability for the generations to follow. I am an advocate for mining and using our own natural resources.

Producing and processing the sustainable energy supplies needed to satisfy future needs are not always clean, pristine, or non-intrusive activities. The truth is that the processes used for mining coal or drilling for oil and natural gas can cause or release toxic byproducts. These chemicals and waste products can contaminate the air, soil, and water.

A classic example of the significant environmental impact of mining an energy source can be seen in the practice of mountaintop mining. Mountaintop mining is a form of surface coal mining in which explosives are used to access coal seams, generating large volumes of waste that bury adjacent streams. The resulting mountaintop waste that then fills valleys and streams can significantly compromise water quality, often causing permanent damage to ecosystems and rendering streams unfit for drinking, fishing, and swimming. It is estimated that almost 2000 miles of Appalachian headwater systems have been buried by mountaintop coal mining (USEPA, 2011).

The Bottom Line: As a practicing environmental professional, I recognize that we must achieve a balance between protecting the air, water, soil, and ecosystems that life on Earth depends on and utilizing the natural resources that Earth possesses. It is from this perspective—maintaining a balance between resource mining and environmental protection—that I present the material in this text. When we split rocks in the wilderness we must be cognizant of the surroundings, whether they be visible on the surface or invisible far below the ground. Obtaining what we need from Mother Earth should be done without injuring the source.

1.7 Thought-Provoking Discussion Questions

1. Do you believe that fracking operations cause earthquakes?
2. If it is proven that earthquakes are caused by fracking operations, do you think we should still frack for natural gas?

3. Is the environment just one of those things that will have to take a few bruises while we explore for and extract more hydrocarbons that we need to sustain our way of life?
4. Are environmental concerns real or just talking points for radical groups?
5. Can we always protect the environment from human-caused damage?
6. Should we focus our attention on renewable sources of energy instead of drilling for more oil and natural gas?
7. Has the Solyndra scandal stymied our efforts to switch from hydrocarbon fuel sources to renewable sources?
8. Is natural gas really as clean as the experts say it is?
9. Does fracking contribute to global warming? How?
10. Who do you think is more responsible for pollution: individuals, companies, or the government?

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2

Shale Gas

Drill here. Drill now. Pay less.

—Newt Gingrich

2.1 Importance of Shale Gas

Natural gas, coal, and oil supply about 85% of the nation's energy, with natural gas supplying about 22% of the total (USEIA, 2008a) (Figure 2.1). Natural gas plays a key role in meeting U.S. energy demands, and its percent contribution to the U.S. energy supply is expected to remain fairly constant for the next 20 years. The United States has abundant natural gas resources—more than 1744 trillion cubic feet (Tcf) of technically recoverable natural gas, including over 300 Tcf of proved reserves (the discovered, economically recoverable fraction of the original gas in place) (USEIA, 2008b, 2010). Technically recoverable unconventional gas (shale gas, tight sands, and coa bed natural gas) accounts for 60% of the onshore recoverable resource. At the 2010 U.S. production rate, approximately 26.86 Tcf, it is estimated that the

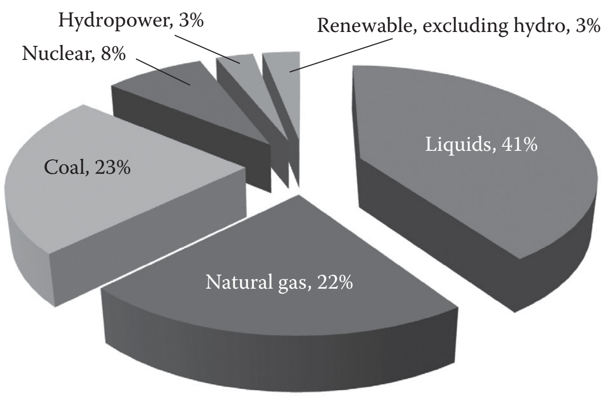

FIGURE 2.1
U.S. energy consumption by fuel. (From USEIA, *Annual Energy Outlook 2008 with Projections to 2030*, U.S. Energy Information Administration, Washington, DC, 2008; www.eia.gov/oiaf/aeo/pdf/0383(2008).pdf.)

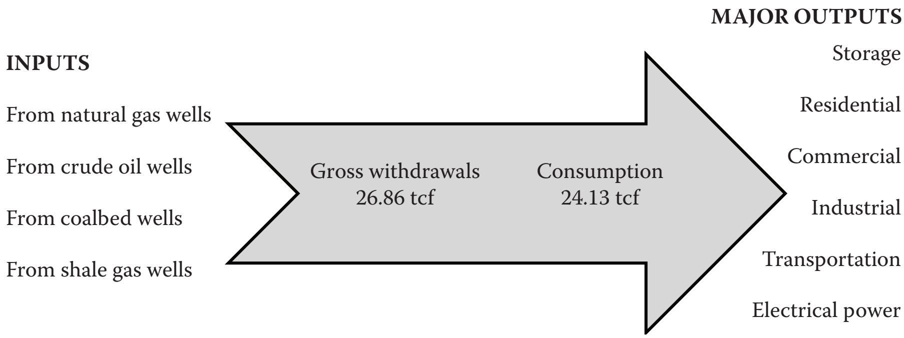

FIGURE 2.2
Natural gas flows in 2010 (trillion cubic feet). (From USEIA, *Total Energy: Natural Gas Flow, 2010 (Trillion Cubic Feet)*, U.S. Energy Information Administration, Washington, DC, 2012; http://www.eia.gov/totalenergy/data/annual/diagram3.cfm.)

current recoverable resource could provide enough natural gas to supply the United States for the next 110 years (USEIA, 2012) (Figure 2.2). Note that, historically, estimates of the size of the total recoverable resource have grown over time as knowledge of the resource has improved and recovery technology has advanced. Unconventional gas resources are a prime example of this trend; for example, U.S. proved reserves of wet natural gas increased by 11% in 2009 to 284 Tcf (USEIA, 2010).

As shown in Figure 2.3, natural gas use is distributed across several sectors of the economy. In addition to serving a vital role in residential heating, natural gas is an important energy source for the industrial, commercial, and electrical generation sectors. Although forecasts vary in the outlook for

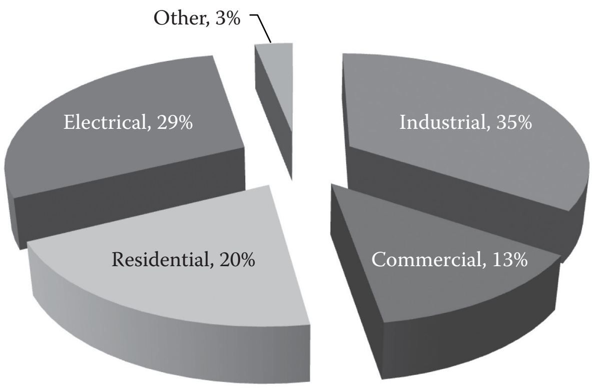

FIGURE 2.3
Natural gas use by sector. (From USEIA, *March 2009 Monthly Energy Review*, U.S. Energy Information Administration, Washington, DC, 2009; www.eia.gov/totalenergy/data/monthly/previous.cfm#2009.)

DID YOU KNOW?

The use of *unconventional* to describe a gas resource is open to interpretation; as technology advances and discrete reservoirs become limited, the reserves considered unconventional a few decades ago are more commonly viewed as conventional by modern standards (Santoro et al., 2011). In this book, *conventional* refers specifically to discrete reservoirs of associated or unassociated natural gas, and *unconventional* refers to tight-gas formations.

future demand for natural gas, they all have one thing in common: Natural gas will continue to play a significant role in the U.S. energy picture for some time to come (USDOE, 2009; USEIA, 2010).

Natural gas, due to its clean-burning nature and economical availability, has become a very popular fuel for the generation of electricity (NaturalGas.org, 2008a). In the 1970s and 1980s, the choice for the majority of electrical utility generators was primarily coal or nuclear power, but, due to economic, environmental, technological, and regulatory changes, natural gas has become the fuel of choice for many new power plants. In 2007, natural gas accounted for 39.1% of electric industry productive capacity (USEIA, 2008b).

Natural gas is the fuel of choice for a wide range of industries (USEIA, 2002). It is a major fuel source for pulp and paper, metals, chemicals, petroleum refining, and food processing. These five industries alone account for almost three quarters of industrial natural gas use and together employ 4 million people in the United States (Bureau of Labor Statistics, 2007). Natural gas is also a feedstock for a variety of products, including plastics, chemicals, and fertilizers. Industrial use of natural gas accounted for 6.63 Tcf of demand in 2007 and was expected to grow to 6.82 Tcf by 2010. It is interesting to note that for many products, there is no economically viable substitute for natural gas.

A look at basic natural gas statistics, however, reveals that natural gas is being consumed by the U.S. economy at a rate that exceeds domestic production, and the gap is increasing (USEIA, 2011). Despite possessing a large resource endowment, the United States consumes natural gas at a rate requiring rapid replacement of reserves. Ambrose et al. (2008) estimated that the gap between demand and domestic supply will grow to nearly 9 Tcf by the year 2025. The good news is that many believe that unconventional natural gas resources such as shale gas can significantly alter that balance.

DID YOU KNOW?

Half of the natural gas consumed today is produced from wells drilled within the last 3.5 years (IPAMS, 2008).

Without domestic shale gas and other unconventional gas production, the gap between demand and domestic production will widen even more, leaving imports to fill the need. Worldwide consumption of natural gas is also increasing; therefore, the United States can anticipate facing an increasingly competitive market for these imports. This increased reliance on foreign sources of energy could pose at least two problems for the United States: (1) it would serve to decrease our energy security, and (2) it could create a multibillion dollar outflow to foreign interests, thus making such funds unavailable for domestic investment.

2.2 Versatility of Natural Gas

From lighting streetlamps and houses in the 1800s and early 1900s, natural gas usage has advanced by leaps and bounds because of its versatility. Because of its high Btu content, an extensive and improved distribution network, and advancements in technology, natural gas has become easy to use in various applications and is now the energy source of choice of many. Natural gas is also reliable—84% of the natural gas consumed in the United States is produced in the United States, and 97% of the gas used in this country is produced in North America (USEIA, 2008b).

Although our supply of natural gas will eventually be depleted, during this depletion process (about 100 years or more) American ingenuity and innovation should be applied to developing a viable hydrogen fuel cell or other energy replacement system that can power our trucks, cars, ships, and airplanes of the future. For the time being, though, it must be all about innovation and natural gas. Moreover, energy innovation must be the first step taken toward replacing lost American jobs. Consider our current economic conditions: bankruptcies, foreclosures, and high unemployment rates. Although it is true that unemployment wounds, it is also true that these wounds can be healed. Again, we must begin this process by converting from gasoline to natural gas. Natural gas conversion is not the panacea for all our energy needs; however, it can be a lifeline to get us off foreign oil and other energy imports and on our way to innovation via renewable energy. Keep in mind that the United States has natural gas reserves (both dry and liquid natural gas) that exceed 200 Tcf, which should be enough natural gas to get us through this century.

In hindsight, ideally, if the Obama administration had taken that TARP or stimulus money and put it to work on natural gas conversion, we would be in better shape today. In January 2009, the new administration could have sat down with the troubled automobile manufacturers and told them, first, that the government was going to bail them out by giving them money to stabilize their situation and, second, that all new cars must be built to run on natural gas only. At the same time, the government should have paid for the approximately 122,000 gas stations in the United States (Census Bureau, 2002) to convert to natural gas. This conversion to natural gas would have made us less dependent on unstable foreign countries and the delivery system less subject to interruption.

Natural gas conversion offers several advantages: Natural gas is efficient and clean burning. Of all the fossil fuels, natural gas is by far the cleanest burning. It emits approximately half the carbon dioxide (CO_2) compared to coal, and the levels of other air pollutants are low. Along with emitting low levels of carbon dioxide, natural gas also emits water vapor; thus, combustion of natural gas produces the same compounds that people exhale when breathing. Oil and coal are composed of much more complex organic molecules with greater nitrogen and sulfur content. Their combustion byproducts include larger quantities of CO_2 (see Table 2.1), nitrogen oxides (NO_x), sulfur dioxide (SO_2), and particulate ash (see Table 2.2). By comparison, the combustion of natural gas liberates very small amounts of SO_2 and NO_x, virtually no ash, and lower levels of CO_2, carbon monoxide (CO), and other hydrocarbons (NaturalGas.org, 2008b).

DID YOU KNOW?

Of all the fossil fuels, natural gas is by far the cleanest burning.

Many environmental activists, with regard to so-called benign fossil fuel sources, view natural gas as the White Knight who will rescue the planet from the pollution of the Red Knight industrialists. Because natural gas emits only half as much CO_2 as coal and approximately 30% less than fuel oil, it is generally considered to be central to energy plans focused on the reduction of greenhouse gas (GHG) emissions (Navigant Consulting, 2008). Because CO_2 makes up a large fraction of U.S. GHG emissions, increasing the role of natural gas in U.S. energy supply relative to other fossil fuels would result in lower GHG emissions.

The need for the United States to reduce its dependence on foreign sources of fossil fuels and fossil fuels in general is increasing; however, the transition to sustainable renewable energy sources will no doubt require considerable time, effort, and investment in order for these sources to become economical enough to supply a significant portion of the nation's energy consumption. It has been estimated that fossil fuels (oil, gas, and coal) will supply 82.1% of the nation's energy needs in 2030 (USEIA, 2008a). Because natural gas is the cleanest burning of the fossil fuels, an environmental benefit could be realized by shifting toward proportionately greater reliance on natural gas until such time as sources of alternative energy are more efficient, economical, and widely available. Moreover, the move toward sustainable renewable energy sources, such as those discussed below, requires that a supplemental

TABLE 2.1

U.S. Carbon Dioxide Emissions from Energy and Industry, 1990–2008

	Carbon Dioxide Emissions (Million Metric Tons Carbon Dioxide)									
Fuel Type/Process	**1990**	**1995**	**2000**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Petroleum	2185.9	2208.4	2461.3	2469.9	2516.7	2605.4	2625.7	2594.9	2588.6	2436.0
Coal	1803.4	1899.9	2138.1	2077.2	2115.6	2140.3	2161.0	2129.9	2154.5	2125.2
Natural gas	1024.7	1183.7	1240.6	1229.5	1194.6	1195.4	1176.1	1157.1	1231.2	1241.0
Renewables[a]	6.1	10.2	10.4	13.0	11.7	11.4	11.5	11.8	11.6	11.6
Energy total	5020.1	5302.3	5850.4	5789.6	5838.6	5952.5	5974.3	5893.7	5986.4	5814.4

Source: USEIA, *Emissions of Greenhouse Gases Report*, U.S. Energy Information Administration, Washington, DC, 2009 (www.eia.gov/oiaf/1605/ggrpt/carbon.html).

[a] Includes emissions from electricity generation using nonbiogenic municipal solid waste and geothermal energy.

TABLE 2.2

Combustion Emissions (Pounds/Billion Btu of Energy Input)

	Combusted Source		
Air Pollutant	**Natural Gas**	**Oil**	**Coal**
Carbon dioxide (CO_2)	117,000	164,000	208,000
Carbon monoxide (CO)	40	33	206
Nitrogen oxides (NO_x)	92	448	457
Sulfur dioxide (SO_2)	0.6	1122	2591
Particulates (PM)	7.0	84	2744
Formaldehyde	0.750	0.220	0.221
Mercury (Hg)	0.000	0.007	0.016

Source: USEIA, *Natural Gas 1998: Issues and Trends*, U.S. Energy Information Administration, Washington, DC, 1999 (www.eia.gov/oil_gas/natural_gas/analysis_publications/natural_gas_1998_issues_and_trends/it98.html).

energy source be available when weather conditions and electrical storage capacity prove challenging. Such a backstop energy source and a temporary bridge until renewable energy sources are refined must be widely available on near instantaneous and continuous demand. The availability of extensive natural gas transmission and distribution pipeline systems makes natural gas uniquely suitable for this role; therefore, natural gas is an integral part of the effort to move forward with alternative energy options. With the current emphasis on the potential effects of air emissions on global climate change, air quality, and visibility, cleaner fuels such as natural gas are important to our nation's energy future (IPAMS, 2008; Navigant Consulting, 2008).

2.3 Alternative or Renewable Energy*

Before continuing our discussion of shale-derived natural gas, it is important to touch upon alternatives to all fossil fuels, or renewable energy. As mentioned, the worldwide use of liquid fossil fuels and their decreasing availability along with the politics involved and other economic forces are pushing for substitute, alternative, or renewable fuel sources. This is the case, of course, because of the current and future economic problems that $4+/gal gasoline have generated (especially in the United States) and because of the perceived crisis developing with high carbon dioxide emissions, the major contributing factor of global climate change. It is important to make a clear distinction between alternative and renewable energy. *Alternative energy* is an umbrella term that refers to any source of usable energy intended to replace fuel sources without the undesired consequences of the replaced fuels. The term "alternative" presupposes an undesirable connotation for fossil fuels (for many people, the term "fossil fuel" has joined that endless list of four-letter words). Alternative energy is fuel energy that does not use up natural resources or harm the environment. Examples of alternative fuels include petroleum as an alternative to whale oil, coal as an alternative to wood, alcohol as an alternative to fossil fuels, and coal gasification as an alternative to petroleum. The key point in understanding alternative energy is that these fuels need not be renewable.

Renewable energy is energy generated from natural resources—such as sunlight, wind, water (hydro), ocean thermal, wave and tide action, biomass and geothermal heat—that are naturally replenished and thus renewable. Renewable energy resources are virtually inexhaustible—they are

* Much of the information and data in this section are from USEIA, *Renewable Energy Trends 2004*, U.S. Energy Information Administration, Washington, DC, 2005 (ftp://ftp.eia.doe.gov/renewables/062804.pdf); USEIA, *How Much Renewable Energy Do We Use?*, U.S. Energy Information Administration, Washington, DC, 2010 (www.eia.gov/energy_in_brief/renewable_energy.cfm).

replenished at the same rate as they are used—but they are limited in the amount of energy that is available per unit time. If we have not come full circle in our cycling from renewable to nonrenewable back to renewable, we are getting close. Consider, for example, that in 1850, about 90% of the energy consumed in the United States came from renewable energy resources (e.g., hydropower, wind, burning wood). Today, though, the United States is heavily reliant on nonrenewable fossil fuels (natural gas, oil, and coal). In 2009, about 7% of all energy consumed and about 8.5% of total electricity production was from renewable energy resources.

Currently, most of the renewable energy is used to generate electricity, provide heat for industrial processes, and heat and cool buildings, as well as for transportation fuels. Electricity producers (utilities, independent produces, and combined heat and power plants) accounted for 51% of the total U.S. renewable energy consumed in 2007 for producing electricity. Most of the rest of the remaining renewable energy consumed was biomass, which was used for industrial applications (principally papermaking) by plants producing only heat and steam. Biomass is also used for transportation fuels (ethanol) and to provide residential and commercial space heating. The largest share of renewable-generated electricity comes from hydroelectric energy (71%), followed by biomass (16%), wind (9%), geothermal (4%), and solar (0.2%). Wind-generated electricity increased by almost 21% in 2007 over 2006, more than any other energy source. Its growth rate was followed closely by solar, which increased by over 19% in 2007 compared to 2006.

From Table 2.3 it is obvious that currently there are five primary forms of renewable energy: solar, wind, biomass, geothermal, and hydroelectric. Each of these holds promise and poses challenges regarding future development. The United States imports more than 50% of its oil. Replacing some of our petroleum with fuels provided from solar power or made from organic plant matter, for example, could save money and strengthen our energy security.

Renewable energy is plentiful, and the technologies are improving all the time. There are many ways to use renewable energy. Our main focus should be on finding and developing a renewable source of liquid fuels (e.g., developed from biomass), because our economy runs on liquid fuels. Most of the non-liquid renewable energies will not (at the present time) provide power for airplanes and heavy trucks; that is, neither fuel cells nor solar, wind, hydroelectric, geothermal, or wave and tidal energy can power the main transportation vehicles we use today. Note that trains have not been mentioned. Many trains today are powered by diesel or diesel–electric systems. If necessary, trains could be retrofitted to steam power developed by burning coal and wood products (a step back into the past); however, this cannot be done to power heavy trucks and airplanes.

Most Americans still do not understand that we are running short of the fuels that we use every day—the fuels that made us what we are today. We built the world's greatest economy on oil that sold for \$3 to \$4 per barrel

TABLE 2.3

U.S. Energy Consumption by Energy Source, 2009

Energy Source	Energy Consumption (quadrillion Btu)
Total	94.820
Fossil fuels (coal, coke, natural gas, petroleum)	78.631
Electricity net imports	0.116
Nuclear electric power	8.328
Renewable energy	7.745
Biomass (biofuels, waste, wood, and wood-derived)	3.884
Biofuels	1.546
Waste	0.447
Wood-derived fuels	1.891
Geothermal energy	0.373
Hydroelectric, conventional	2.682
Solar thermal/photovoltaic energy	0.109
Wind energy	0.697

Source: USEIA, *U.S. Energy Consumption by Energy Source*, U.S. Energy Information Administration, Washington, DC, 2010 (www.eia.gov/cneaf/alternate/page/renew_energy_consump/table1.html).

of oil. That is no longer the case. In order to maintain our current level of living, the so-called good life, we must find and develop renewable energy sources to power and secure our future. In the meantime, we should mine our reserves of natural gas to the fullest extent possible and hope that by the time we exhaust our natural gas supplies we will have discovered practical sources of sustainable renewable energy (Spellman and Bieber, 2011).

DID YOU KNOW?

Natural gas used by consumers is composed almost entirely of methane (USDOT, 2011).

2.4 The 411 on Natural Gas

Natural gas is a combination of hydrocarbon gases consisting primarily of molecules that range from one to four carbon atoms in length. The gas with one carbon atom in the molecule is methane (CH_4), with two is ethane (C_2H_6), with three is propane (C_3H_8), and with four is butane (C_4H_{10}). All are paraffin-type hydrocarbon molecules. A typical natural gas composition, including