

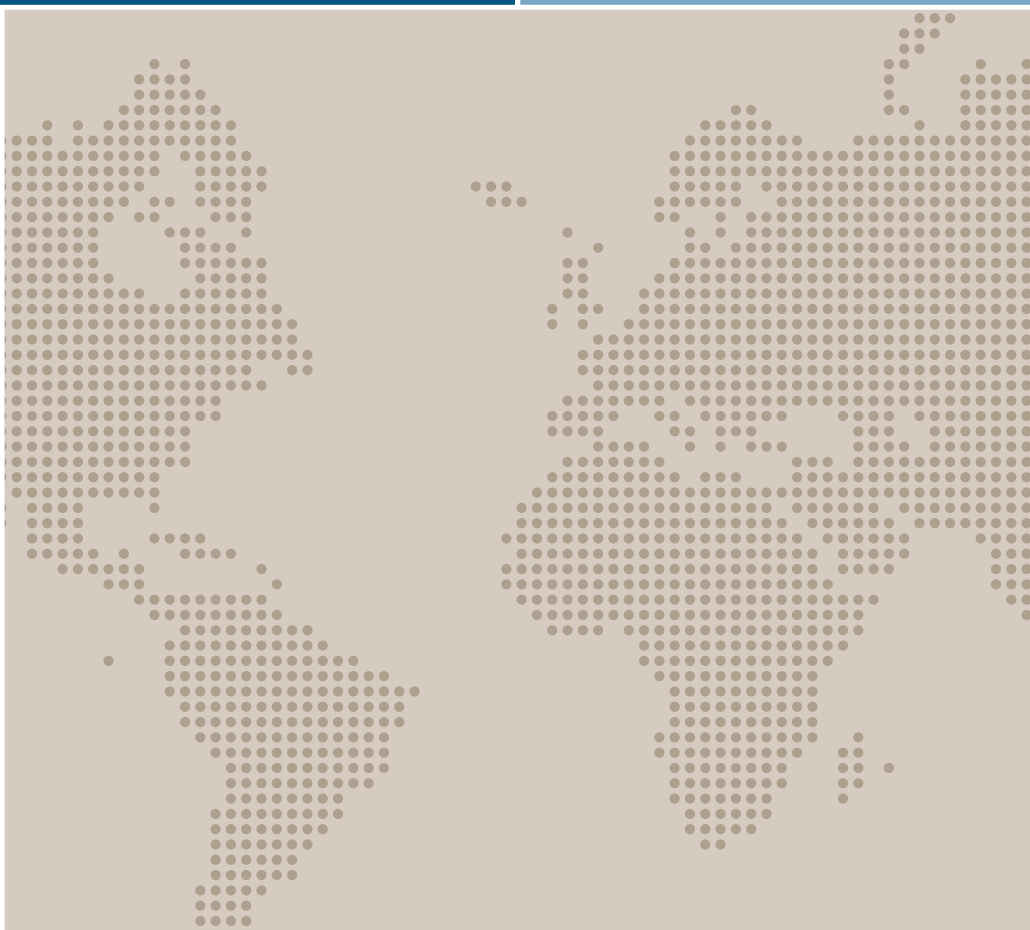
Developing America's Unconventional Gas Resources

Benefits and Challenges

A Report of the CSIS Energy & National Security Program

AUTHORS
Frank Verrastro
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DEVELOPING AMERICA'S UNCONVENTIONAL GAS RESOURCES BENEFITS AND CHALLENGES

Frank Verrastro and Conor Branch¹

Summary

Access, higher prices, and advances in technology have made it possible to commercially develop unconventional gas resources. The magnitude and potential impact of this resource has attracted a great deal of public- and private-sector interest, as well as increasing scrutiny. The ability to produce increasing volumes from the United States' vast shale reserves has the potential to reduce U.S. import reliance, reduce greenhouse gas (GHG) emissions, increase global gas supplies, and potentially alter the way gas is marketed globally, thereby conferring substantial economic, security, and environmental benefits for both the United States and the world at large. However, failure to manage some of the attendant impacts surrounding the development of this resource at scale could seriously hamper efforts to fully realize those benefits. Such impacts include water concerns (primarily focused on prevention of groundwater contamination, water use at scale, and the treatment, recycling, and disposal of produced water volumes); issues surrounding the public disclosure of the composition of fracking fluids; the “industrialization” of rural areas during development, evidenced by increased congestion, road construction, noise, haze, fugitive emissions, and infrastructure development; and local issues related to widely differing lease arrangements, population density, property values, tax revenue streams, and land use. This paper seeks to put the strategic value of this resource in context, outline the potential benefits and challenges to its development, and suggest strategies and actions for charting a responsible path forward.

Background

Access, higher prices and advances in technology, namely the combination of horizontal drilling and hydraulic fracturing (“fracking”), have made it possible to economically develop unconventional shale gas resources in the United States.

¹ The ongoing analysis on natural gas and the geopolitics of energy collectively represents the insights and analyses provided by the staff of the CSIS Energy and National Security Program, as well as contributions made by outside colleagues. The authors would like to thank in particular Guy Caruso, Alan Hegburg, Dave Henderson, Lisa Hyland, and Dave Pumphrey for their comments and contributions to this paper.

With respect to employment impacts, U.S. employment in natural gas rose 17 percent from 2006 to 2008, representing one in four net new jobs created during that time throughout the entire U.S. economy. Natural gas supports an estimated 2.8 million U.S. jobs, and over 30 states are home to more than 10,000 natural gas jobs each. A 2009 Penn State study concluded that the Marcellus shale could generate \$13.5 billion in economic value per year, \$1.4 billion in state and local tax revenue, and almost 175,000 jobs by 2020—in Pennsylvania alone.²

From an environmental perspective, natural gas can play a pivotal role in the nation's transition to a low-carbon future. Twice as clean as coal and significantly underutilized today, natural gas presents the only option of adequate scale over the next 10 years to begin immediately to make a meaningful difference in reducing the nation's carbon footprint. Natural gas also is an essential partner to the development of renewables, providing cleaner, reliable backup power when the sun is not shining or the wind dies down. In addition to its increased role in power generation, gas can also contribute (albeit on a more limited basis) to reducing petroleum use in transportation.

Although the upper limits of the United States' vast natural gas supplies remain uncertain, there is broad consensus—from the U.S. Geological Survey and the U.S. Department of Energy to the Potential Gas Committee (PGC) and Cambridge Energy Research Associates (CERA)—that our nation has enough domestic supplies of natural gas to power the United States for generations. The Potential Gas Committee in June 2009 reported that the United States has 1,836 trillion cubic feet (Tcf) of technically recoverable gas.³ A single Tcf of natural gas is enough to meet the energy needs of 1 million households for three years. A 2010 IHS CERA report analyzing the emerging gas plays in North America suggested an aggregate resource base of some 2,000 Tcf and a total, including what is “expected “ to be found in the future, of over 3,000 Tcf—giving rise to claims that such available supplies are able to meet current consumption needs for over 100 years.⁴

The upside of vast domestic natural gas abundance and underutilization of existing infrastructure is that this clean energy can be called into action very quickly. According to the most recent figures published by the U.S. Energy Information Administration (EIA), natural gas generators make up the largest portion of the U.S. generating fleet (41 percent of installed capacity compared to 30 percent for coal). Yet 45 percent of the nation's electricity was generated by coal-fired power plants, compared to just 24 percent by natural gas. Using modern generating technology, natural

² Timothy Considine et al., “An Emerging Giant: Prospects and Economic Impacts of Developing the Marcellus Shale Natural Gas Play,” Department of Energy and Mineral Engineering, Pennsylvania State University, University Park, Pa., July 2009, <http://www.allegHENYconference.org/PDFs/PELMisc/PSUStudyMarcellusShale072409.pdf>.

³ Potential Gas Committee (PGC), “Potential Gas Committee Reports Unprecedented Increase in Magnitude of U.S. Natural Gas Resource Base,” news release, June 18, 2009, <http://www.aga.org/NR/rdonlyres/65B2FD7E-A208-4687-9B4B-6EC079DA673D/0/0906PGCPRESS.PDF>.

⁴ IHS Cambridge Energy Research Associates (CERA), “Fueling North America's Energy Future: The Unconventional Natural Gas Revolution and the Carbon Agenda: Executive Summary,” 2010, http://www2.cera.com/docs/Executive_Summary.pdf.

gas releases less than half the CO₂ per megawatt hour of a coal plant. And, modern combined cycle turbines emit only about 40 percent of the CO₂ of a typical coal plant. According to the Congressional Research Service, if we doubled the utilization of this capacity, we could displace about 19 percent of CO₂ emissions from coal power.

That said, however, the exploitation of this enormous resource is not without challenges. As with other conventional and nonconventional energy resources, an enormous endowment of “molecules in the ground” does not always translate into producible volumes, as a variety of “above-ground” factors tend to influence or otherwise determine the pace and scale at which even technically recoverable resources can be brought to market. Realizing the full promise of shale gas resources will require overcoming a variety of technical, economic, environmental, regulatory, and societal challenges.

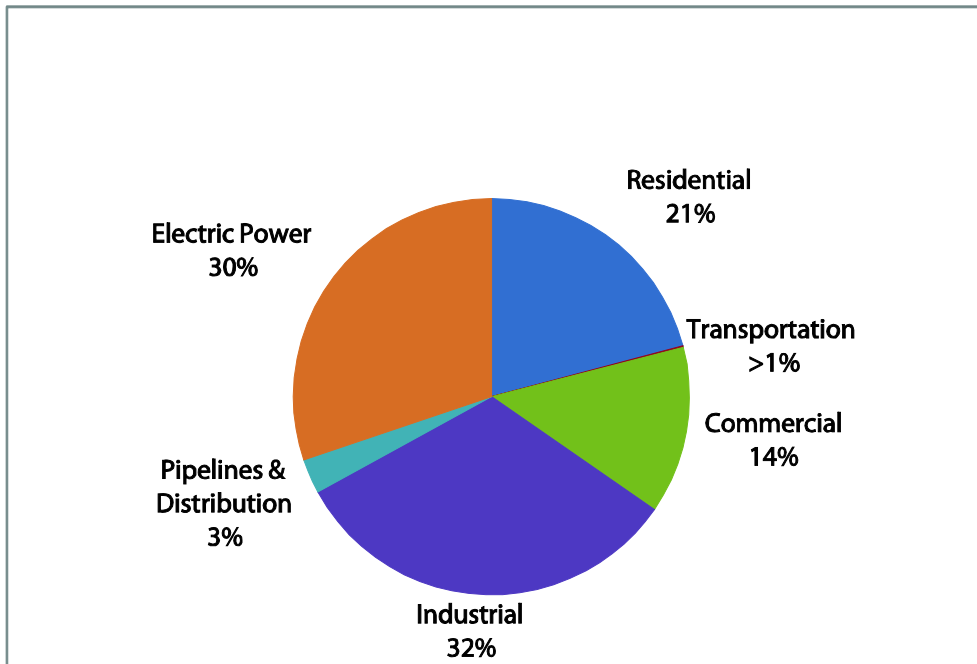
For example, all shales are not alike, so the application of drilling and reservoir fracturing technology and operational experience matters. Steep decline rates require ongoing investment and continued drilling with repeated fracking. The upfront investment in terms of acquiring lease acreage and pilot wells is not insignificant and must be weighed against prevailing and projected changes in costs and commodity prices, which historically have been volatile. On the environmental front, while water concerns (primarily focused on prevention of groundwater contamination, water use at scale, and (produced) water treatment, recycling, and disposal) are paramount, issues surrounding the public disclosure of the materials contained in fracking fluid, the “industrialization” of rural areas during development (e.g., road construction and congestion), noise, haze, fugitive emissions, and infrastructure development, and local issues relating to widely differing lease arrangements, population density, property values, local tax revenue streams, and land use can also be significant factors.

As a consequence, in order to ensure the timely development of economic and reliable sources of domestic gas, produced in an environmentally sound manner, government and industry must work collaboratively with local stakeholders and regulators to develop and enforce appropriate safeguards and best practices that address, in turn, each of these potential barriers.

Resource Assessment, Current Production, and Consumption

Natural gas is a highly versatile energy source that currently plays a key role in virtually all sectors of the economy (electric power generation, residential and commercial heating, and as a feedstock for a variety of products and industrial processes). Transportation is a notable exception where gas currently plays a minimal role, mostly for use in limited radius fleet vehicles and public transit (buses, taxi cabs, etc.). It is known as the “cleanest” fossil fuel due to its lower carbon, sulfur dioxide, nitrous oxide, and mercury emissions per unit of energy.

Figure 1. U.S. Natural Gas Consumption by Sector, 2009



Data source: EIA, *Monthly Energy Review*, May 2010.

Global Natural Gas Supply

The recent MIT study, *The Future of Natural Gas*, estimates that there is a mean global supply of natural gas equal to 16,200 Tcf, which based on current consumption patterns equates to approximately 150 years of supply.⁵ This estimate takes into account conventional gas supplies around the world and both conventional and unconventional sources within the United States and Canada. Increasingly, unconventional gas is looked to as a promising source of significant additional global supply, although many nations currently lack adequate seismic work, infrastructure, regulatory and ownership protocols, and an experienced service sector necessary to duplicate the U.S. experience anytime soon. Consequently, a great deal of work would have to be done to both prove up international reserves and realize significant expansion of unconventional shale production outside of North America.

U.S. Natural Gas Supply

Within the United States, natural gas resource assessments have undergone significant upward revisions in recent years. A 2008 Navigant Consulting study found that the United States

⁵ MIT Energy Initiative, *The Future of Natural Gas: An Interdisciplinary Study: Interim Report* (Cambridge, Mass: Massachusetts Institute of Technology, 2010), p. 7, <http://web.mit.edu/mitei/research/studies/report-natural-gas.pdf>.

possesses a mean resource base of 1,680 Tcf, of which shale gas plays account for 274 Tcf.⁶ A 2009 report by the Potential Gas Committee found that the United States has a potential future supply of 2,074 Tcf (with shale gas accounting for 616 Tcf).⁷ The 2009 PGC figure represents a 39 percent upward revision from their 2006 resource assessment, stemming (almost entirely) from increased unconventional natural gas estimates.⁸ The 2010 IHS CERA report, “Fueling North America’s Energy Future,” identified an aggregate discovered resource base of 2,000 Tcf and a possible future base of 3,000 Tcf.⁹ Approximately 15 percent of this resource is located within Alaska, while the remaining amounts are found in the continental United States and offshore. The lower 48 states are believed to contain unconventional natural gas resources that comprise 55 to 60 percent of the total natural gas resource base.¹⁰

U.S. Natural Gas Production

In 2009, as a result of both reduced Russian production (partly due to lower gas demand in Europe) and the success of unconventional gas development in the lower 48 states, the United States displaced Russia as the largest producer of natural gas in the world.¹¹ Traditionally, U.S. natural gas supplies have come from conventional onshore and offshore production, but that production profile has begun to change. The aging of conventional gas fields, combined with decreasing discoveries of new replacement fields, is projected to yield substantially reduced gas production volumes from conventional sources over the next 25 years. To offset these production declines, unconventional natural gas is expected to comprise an increasingly larger portion of the U.S. natural gas market. Among the unconventional gas resources (i.e., shale, coal bed methane, and tight sands gas), shale gas is projected to undergo the largest production increase.

⁶ Navigant Consulting Inc., “North American Natural Gas Supply Assessment: Executive Summary and Update,” July 2008, http://www.afdc.energy.gov/afdc/pdfs/ng_supply_assessment_2.pdf.

⁷ PGC, “Potential Gas Committee Reports Unprecedented Increase in Magnitude of U.S. Natural Gas Resource Base.”

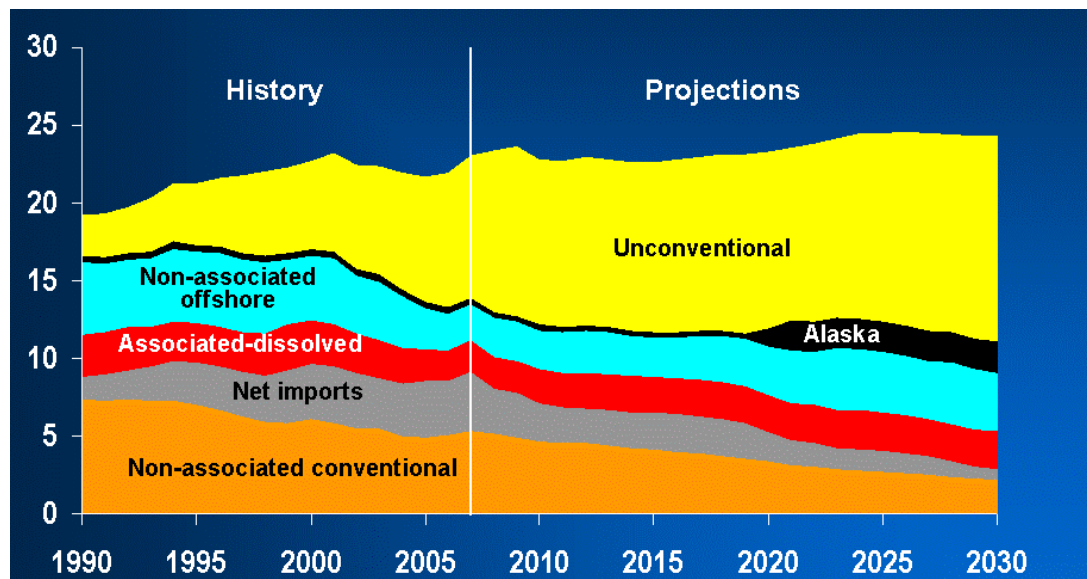
⁸ Ibid.

⁹ IHS CERA, “Fueling North America’s Energy Future.”

¹⁰ MIT Energy Initiative, *The Future of Natural Gas*, p. 9.

¹¹ Upstream staff, “US passes Russia as top gas producer,” Upstreamonline.com, January 12, 2010, <http://www.upstreamonline.com/live/article203335.ece>.

Figure 2. U.S. Natural Gas Production



Source: EIA, *Annual Energy Outlook 2009*, p. 4.

U.S. Natural Gas Imports/Exports

In 2009, the United States imported approximately 3.75 Tcf of natural gas, the overwhelming majority (87 percent) of which is delivered via pipeline from Canada. Far smaller amounts of natural gas are delivered in the form of liquefied natural gas (LNG) from Egypt, Nigeria, Norway, Qatar, Trinidad, and Yemen. A very small amount of natural gas is delivered to the United States from Mexico every year as well.¹²

Types and Locations of Major U.S. Unconventional Gas Deposits

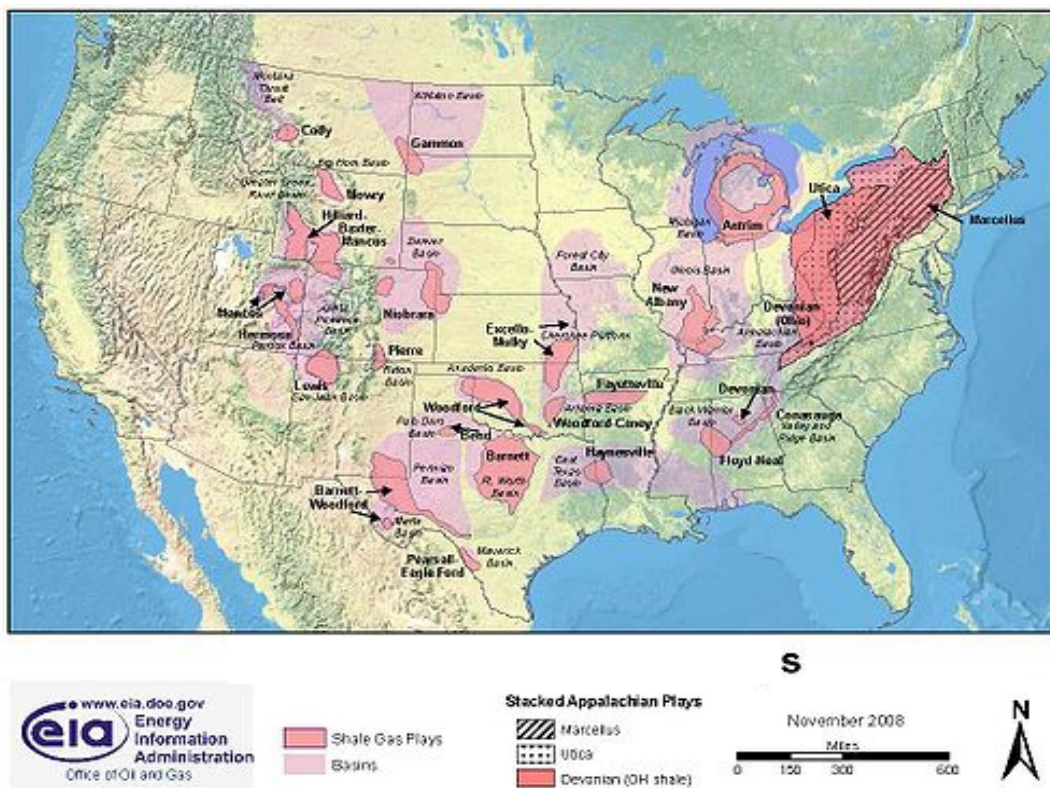
Devonian shales, coal bed methane (CBM), and tight sands deposits are routinely characterized as unconventional sources of natural gas. What distinguishes these unconvensionals from conventional gas is the porosity and permeability of the formations. To free up, move, and extract gas from such formations requires increasing the porosity of the reservoir and creating migration or evacuation routes for the gas to move to the production wells. Consequently, fracturing of the formation and the inclusion of proppants to keep the migration pathways open are production processes frequently associated with the development of unconventional resources. Methane hydrates are also considered to be an unconventional gas resource, but given the technological hurdles and lead times required for hydrates to be commercially viable, they are not included, except by reference, in this analysis.

¹² EIA, "U.S. Natural Gas Imports by Country," http://www.eia.doe.gov/dnav/ng/ng_move_imp_c_s1_m.htm.

Location of Major Unconventional Gas Deposits

In the United States, significant unconventional gas resources are concentrated in a number of major “plays” spread across much of the eastern, mountain, and southern regions of the country. At present, exploration and production has been focused on the five “big shales”: the Barnett in Texas; the Haynesville in Louisiana; the Fayetteville in Arkansas; the Woodford in Oklahoma; and more recently, the Marcellus, which runs from southwestern New York State all the way to Kentucky. In addition to the substantial unconventional U.S. natural gas resource base, several additional large plays (e.g., Horn River basin) exist in western Canadian provinces.

Figure 3. U.S. Shale Gas Plays, November 2008



The Natural Gas Opportunity

As described earlier, coal-fired electricity generation dominates the U.S. power market, producing some 45 percent of the electricity consumed. What may come as a surprise to some, however, is that more generation capacity exists for natural gas than coal. The disparity between coal and natural gas generation is explained, in large part, by the price differential between these two fuels, as well as the existence of long-term coal contracts. In May 2010, the average price paid for coal

was \$2.27 per million British thermal units (MMBTU), while the corresponding price for natural gas was more than double at \$4.78.¹³

Table 1. Electricity Production in the United States, 2009

| Fuel Source | Nameplate Capacity | Generation (gWh) | Net Generation Percent | Capacity Factor |
|------------------|--------------------|------------------|------------------------|-----------------|
| Coal | 337,300 | 1,764 | 44.7 | 72.2 |
| Petroleum | 63,655 | 39 | 1.0 | 9.2 |
| Natural gas | 454,611 | 934 | 23.6 | 40.7 |
| Nuclear | 106,147 | 799 | 20.2 | 91.1 |
| Hydroelectric | 77,731 | 272 | 6.9 | 37.2 |
| Other renewables | 16,404 | 141 | 3.6 | NA |
| Wind | 24,980 | 71 | 1.8 | NA |
| Solar PV | 539 | 0.807 | 0.02 | NA |

Source: Compiled from EIA statistical database, <http://www.eia.gov/fuelectric.html>.

Increased Use of Natural Gas in the Power Sector

In addition to being a substantial source of carbon dioxide emissions, the production and combustion of coal produces several other highly undesirable emissions. The combustion of coal is a leading emitter of sulfur dioxide, a leading cause of acid rain; nitrous oxide, a potent greenhouse gas and cause of smog; mercury, a toxin that is known to cause kidney dysfunction, hypertension, and severe skin irritation; as well as several forms of particulates that can aggravate respiratory conditions such as asthma and emphysema. Over the years, coal plants have undergone phased emissions reductions of these chemical compounds, excluding carbon dioxide, although significant emissions continue to be released into the atmosphere.

In comparison to coal, natural gas emits virtually zero sulfur dioxide and mercury. It produces approximately 80 percent less nitrous oxide and roughly half as much carbon dioxide per unit of energy delivered. Natural gas also possesses a series of other comparative advantages over coal, including:

- *“Cycling.”* Natural-fired gas plants have the ability to quickly scale up, or scale down, the quantity of electricity that they produce. The ability to adjust power production levels within minutes has several key advantages for both integration with renewable energy sources and serving as a reliable supply for meeting peak demand.
- *Baseload generation.* In addition to serving as a system balancer or being able to supply peak demand periods, gas is also used as a reliable source for meeting baseload capacity. Due to problems with intermittency and lack of storage capacity, the most likely forms of renewable

¹³ EIA, “Electric Power Monthly,” http://www.eia.doe.gov/cneaf/electricity/epm/epm_sum.html.

electricity growth (e.g., solar and wind) are unable to provide reliable baseload generation capacity. Traditional hydroelectric generation capacity has reached its limit within the continental United States. New nuclear reactors have been mired in permitting issues, stymied by public safety concerns, and constrained by huge capital costs. Natural gas can be counted on to produce economically competitive baseload energy with significantly diminished environmental impacts and carbon emissions when compared against coal, its primary rival.

- *Significant carbon mitigation.* There are two principal ways in which natural gas will significantly reduce the CO₂ emissions in the United States. First, due to its chemical composition, natural gas is an intrinsically lower carbon fuel than coal. Second, the U.S. coal power plant fleet is 15 percent less efficient than the natural gas power plant fleet, requiring additional coal combustion to produce the equivalent quantity of end-use electricity (assuming current technology and infrastructure). This added 15 percent fuel requirement needed to offset efficiency losses is a source of substantial carbon emissions.
- *Affordability.* Provided that natural gas supply is able to keep pace with projected demand growth, natural gas provides a highly cost-effective option for electricity supply both as a provider of baseload electricity and as a “balancer” to compensate for reductions in (intermittent) electricity production from renewables. As projections for global gas continue to grow, coupled with the prospect for potentially rapid increases in domestic unconventional supplies, ample gas volumes should keep U.S. prices affordable well into the next decade when efficiency and renewables growth could be available to moderate future gas demand growth. Examining the levelized cost of electricity (LCOE)¹⁴ suggests that the only competition for natural gas, on a pure price level, is coal. When factoring in the environmental toll of coal-fired electricity generation, the price differential arguably shifts in favor of natural gas. In the presence of a price on carbon emissions, the economic calculus shifts further in favor of natural gas. (See table 2.)
- *Storability.* Natural gas is stored in a variety of forms and locations across the United States. The most common large-scale storage occurs in depleted oil or natural gas reservoirs, aquifers, and salt cavern formations. Far smaller amounts of natural gas are stored in abandoned mines and within storage tanks as either compressed natural gas (CNG) or LNG. Research is currently being conducted to test the suitability of storing natural gas in hard-rock mines, though the technology is not yet proven. These storage facilities are usually located close to population centers and are operated by interstate or intrastate pipeline operators, local distribution companies (LDCs), and independent storage providers.
- *Portability.* For many nations around the globe the lack of indigenous natural gas supplies combined with poorly developed transportation infrastructure has resulted in limited natural gas penetration. These limitations are not broadly applicable in the United States. The United

¹⁴ Levelized cost of electricity (LCOE) is the cost per kWh that over the life of the plant fully recovers operating, fuel, capital, and financial costs.

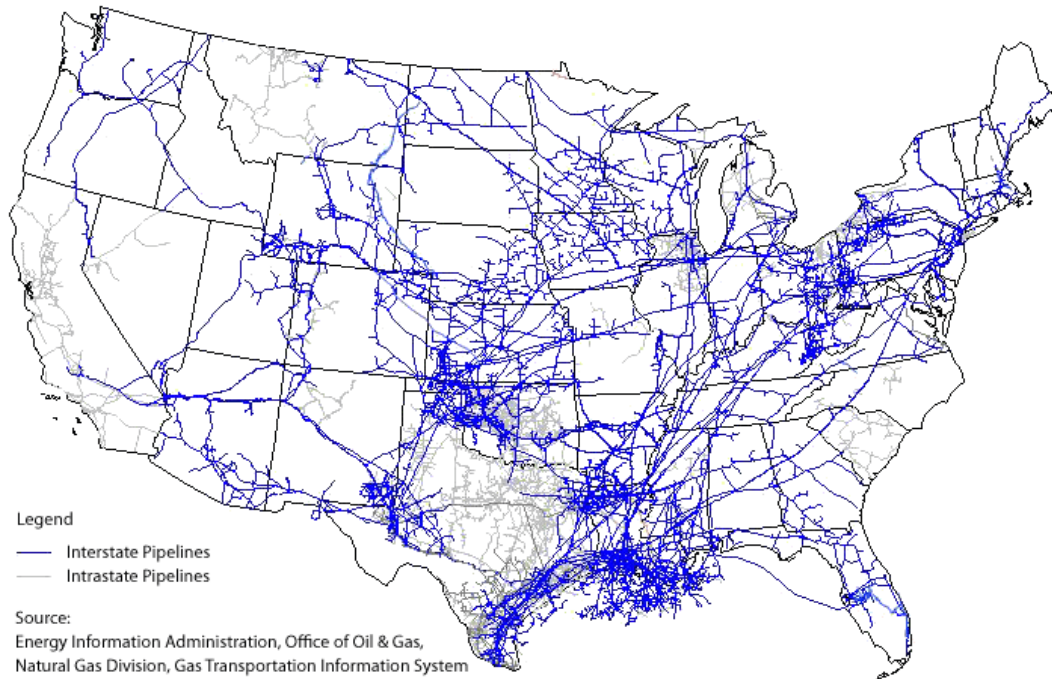
States maintains an extensive network of interstate, as well as intrastate, pipelines that service population centers across the country. Much of the expanded production from unconventional natural gas sources has benefited from being located close to population centers in the East and Great Lakes regions where well-developed pipeline infrastructure already exists. With the infrastructure already in place, the ability to increase the capacity utilization rates of those lines will invariably reduce transportation costs. Historically, transportation and distribution infrastructure costs, combined with the proximity of gas resources to large population/consumption centers, have been key drivers of gas development.

Table 2. Levelized Cost of Electricity (2005 cents/kWh)

| Generation Source | Reference Case |
|-----------------------------|----------------|
| Coal | 5.4 |
| Advanced natural gas (NGCC) | 5.6 |
| Advanced nuclear | 8.8 |
| Renewables | |
| Wind | 6.0 |
| Solar | 8.5 |
| Biomass | 19.3 |
| Wind + gas backup | 10 |

Source: MIT Energy Initiative, *The Future of Natural Gas*, p. 22.

Figure 4. U.S. Natural Gas Delivery System: Pipeline Infrastructure



Economic Impact of Natural Gas Jobs

A 2009 report conducted by IHS Global Insight found that the natural gas industry created more than 2.8 million jobs in 2008 while it added more than \$384 billion to the U.S. economy.¹⁵ Despite the fragile recovery of the U.S. economy over the past six months, unemployment remains stubbornly high at 9.5 percent.¹⁶ The natural gas sector is one of the few domestic industries currently creating jobs.

A 2010 study conducted by Penn State University on the effects of natural gas drilling in the Marcellus shale on the Pennsylvania economy concluded that expanded drilling provided a “direct economic stimulus of \$3.77 billion,” while also growing the state and local tax base by \$389 million and creating 44,000 jobs for the state economy in 2009.¹⁷ The study also found that

¹⁵ IHS Global Insight, “The Contributions of the Natural Gas Industry to the U.S. National and State Economies: Executive Summary,” September 2009, <http://www.anga.us/media/41062/ihs%20-%20united%20states.pdf>.

¹⁶ Bureau of Labor Statistics, “Economic News Release: Employment Situation Summary,” July 30, 2010, <http://www.bls.gov/news.release/empsit.nr0.htm>.

¹⁷ Gary Harmon, “Study: Drilling in Pa. a \$3.77B stimulus,” *Grand Junction (Colo.) Daily Sentinel*, June 5, 2010, http://www.gjsentinel.com/news/articles/study_drilling_in_pa_a_377b_st.

in 2010 the Marcellus shale could produce more than \$8 billion in sales leading to more than \$785 million being funneled into state and local tax coffers and the creation of more than 88,000 jobs.¹⁸

Research performed by the Baton Rouge–based consulting firm Loren C. Scott & Associates found similar job growth and expanded tax revenue coming from the Haynesville play in Louisiana. The study concluded that while Louisiana lost 38,500 jobs in 2009, without the additional work produced as a result of the development in the unconventional natural gas sector, the job loss figure would have been more than double at over 96,000.¹⁹ The study additionally concluded that the added economic activity in the Haynesville play limited the drop in Louisiana’s personal income to 0.7 percent (\$1.2 billion), rather than a 4.3 percent decline (excluding Haynesville activity).²⁰

In Texas, the Perryman Group, an economic consultancy firm, has calculated that drilling activity in the Barnett shale accounted for \$11 billion in economic output and 111,131 jobs in 2008. The study also found that “10.4 percent of the private-sector employment in the Forth Worth area” was attributable to the Barnett.²¹ Records show that the state of Texas received more than \$275 million in severance taxes from Barnett wells over the past year, and the city of Forth Worth projects that it will take in more than \$1 billion in bonus and royalty payments over the next three decades in addition to \$400 million in production taxes.²²

What is clear from these reports is that the expansion of drilling operations into unconventional natural gas resources represents a large economic opportunity for state and local governments to grow their tax bases while providing much needed jobs. It may also be possible for many coal miners who are displaced by increased natural gas penetration to find work in the burgeoning natural gas industry.

Import Displacement

As increasing amounts of indigenous natural gas are produced to meet growing American energy needs, projections for U.S. gas imports inevitably decline. Longer-haul LNG imports from locations such as Egypt and Trinidad are likely to decline first, but pipeline import volumes from Canada may also diminish if the United States is able to meet ambitious production targets for unconventional gas. A decrease in imports means more money spent on indigenous supplies (and domestic job creation), enhanced energy security, and possible decreases in trade imbalances, a key factor in the long-term macroeconomic stability of the United States.

¹⁸ Ibid.

¹⁹ Kirkland, “Energy: Big Money Drives up the Betting on the Marcellus Shale.”

²⁰ Ibid.

²¹ Andrew Maykuth, “Well, Well Neighbor,” Philly.com, April 11, 2010, <http://www.philly.com/philly/business/90552074.html>.

²² Ibid.

Increased LNG Supplies

As U.S. natural gas production increases and LNG exports to the United States decrease, more LNG will become available for purchase by global consumers. Increased LNG availability is particularly useful to Europeans (assuming LNG receiving facilities, pipeline interconnections, and adequate gas storage are constructed), as it would provide them alternate means of natural gas acquisition, thus decreasing their dependence on Russian gas supplies and increasing their overall energy security. A continued surplus of global gas will inevitably force a restructuring of those gas supply contracts that are currently indexed to oil prices.

Additional Global Unconventional Natural Gas Resources

While the United States has been the undisputed leader in the exploitation and development of unconventional gas resources, a number of other nations appear to have the resource potential to (at least partially) duplicate the U.S. model—given the proper regulatory, infrastructure, and pricing conditions and an appropriate amount of time in which to develop indigenous capabilities. A variety of coal bed methane and shale gas opportunities appear to exist in Europe, Turkey, Latin America, China, India, Indonesia, Australia, and elsewhere.

Challenges to Unconventional Natural Gas Development

Notwithstanding the great “promise” attendant to the successful development of unconventional natural gas resources in the United States and elsewhere, what is clear is that such development at scale is not without considerable challenges. In the past few years, as the scale of unconventional gas development has literally exploded—including in geographic areas unfamiliar with large-scale energy development activity—public concern over shale gas exploration, safety and contamination issues associated with the fracking process and frack chemicals, and concerns over water quality and resources has increased.

What Is Hydraulic Fracturing?

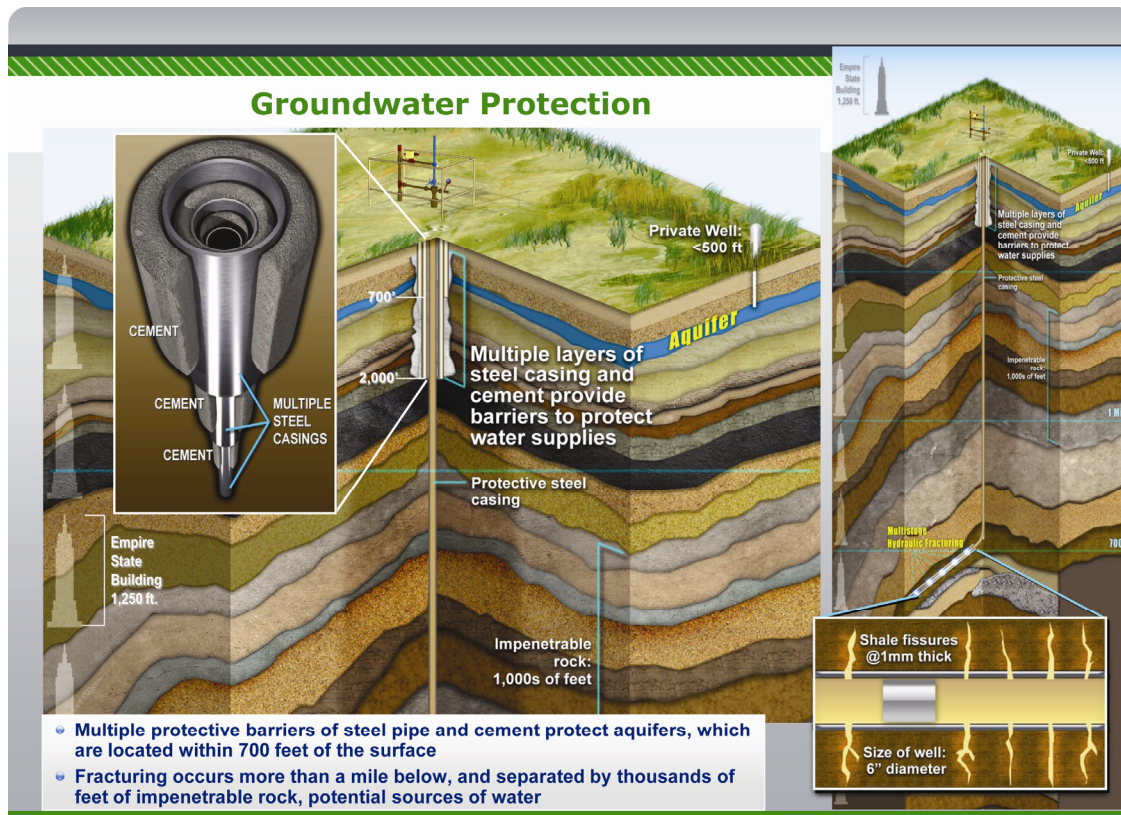
Hydraulic fracturing stimulation is the principal process by which unconventional natural gas deposits are put into production. Despite the recent scrutiny that has increased its media profile, “fracking” is a mature technology that has been widely used for more than 60 years. Hydraulic fracturing has been used in more than 1 million wells around the world, with an additional 35,000 wells drilled using fracking technology every year.²³

During the fracking process a hole is drilled thousands of feet into the earth through a combination of vertical and horizontal drilling techniques. The drill bore cuts through a series of

²³ Energy in Depth, “Frac in Depth: History of Hydraulic Fracturing,” <http://www.energyindepth.org/in-depth/frac-in-depth/history-of-hf/>.

different strata and geologic formations before achieving its desired depth. At several points in the drilling process, the drill string and bit are removed from the wellbore. A metal casing sleeve is then inserted into the wellbore where it is cemented into place. Additional (concentric) casing sleeves and cementing are frequently used to further promote well integrity and add additional barriers in order to prevent contamination of aquifers.

Figure 5. Protecting Surface Water Aquifers from Drilling and Fracking Operations



Source: Courtesy of Anadarko Petroleum Corporation.

When the drill bit has achieved its desired/target depth and location, it is removed from the borehole, and the last section of pipe and cement casing are put in place. Explosive charges are then inserted through the pipe and remotely detonated at the target zone in order to perforate the pipe and casing sleeve. Hydraulic fracturing fluid is then injected into the well at high pressure. As described in greater detail below, the composition of the fracking fluid solution varies from formation to formation, but it is generally composed of water and sand (99.5 percent of the composition) along with a proprietary mix of chemical lubricants and emulsifiers.

The pressure forces the fluid through the perforations in the pipe and into the surrounding formation—shale, CBM, or tight sand—expanding existing fractures and creating new ones in the

process. Sand, or “proppant,” is used to keep the recently created fractures from closing up on themselves thus allowing the liberated natural gas to flow more easily. After the fracking has been completed, much of the fracking fluid returns up through the wellbore where it is stored in containment ponds or storage tanks until it can be properly disposed of.

Once the natural gas has been provided a pathway to escape the formation, it enters the lower pressure area inside of the pipe. The process of perforating and then fracking is often repeated various times along the horizontal portion of the well. Typical shale gas deposits are located several thousand feet below the deepest potential sources of underground drinking water. Further, the low permeability of shale rock and other intervening formation horizons present additional impediments to the flow of fracking chemicals from target zones upward into aquifers. Consequently, the likelihood of water contamination as a consequence of fluids migration up through several thousand feet of strata is extremely unlikely.

Table 3. Shale Target Zones and Aquifer Locations for Major U.S. Shale Basins

| Basin | Depth to Shale (ft) | Depth to Aquifer (ft) |
|--------------|---------------------|-----------------------|
| Barnett | 6,500-8,500 | 1,200 |
| Fayetteville | 1,000-7,000 | 500 |
| Marcellus | 4,000-8,500 | 850 |
| Woodford | 6,000-11,000 | 400 |
| Haynesville | 10,500-13,500 | 400 |

Source: MIT Energy Initiative, *The Future of Natural Gas*, p. 15.

That said, more likely candidates as sources of possible water contamination involve surface activities, including improper well design, inadequate surface casing and substandard or improper cementing, improper handling of surface chemicals, improper design/performance of holding ponds, and improper storage and disposal of wastes and produced water.

In the case of drilling through aquifer formations, by regulation, surface casing is generally required to extend at least 50 to 100 feet below the deepest potential source of drinking water in order to isolate the aquifer from the drilling and production process. In many instances, concentric casing sleeves are utilized to provide additional barriers. Federal, state, and local regulations govern the handling and management of surface activities and disposal, as well as virtually every phase of the drilling and fracking process.

Unconventional Natural Gas Regulation at the State Level

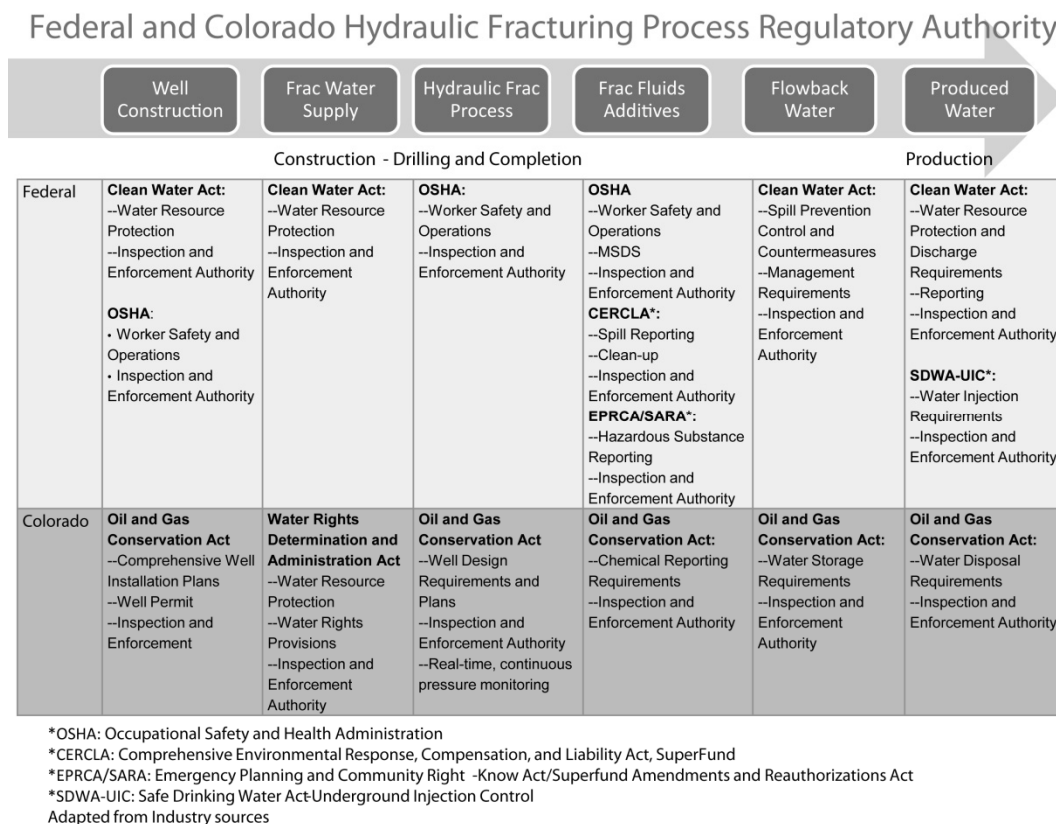
The Safe Drinking Water Act (SDWA), adopted by Congress in 1974, authorized the Environmental Protection Agency (EPA) to regulate the country’s public drinking water supplies to ensure that they posed no risk to public health. The SDWA applies to all public water systems

(private water wells are exempt) and authorizes EPA to establish national health-based standards for drinking water quality. Those standards are then implemented by state and local regulatory agencies under EPA oversight.

Additionally, the SDWA’s Underground Injection Control (UIC) Program regulates the injection of (a wide variety of) fluids into underground formations. For purposes of regulation, EPA has established five “classes” of underground injection wells. Class II wells cover injections associated with oil and gas production.

As part of the 2005 Energy Policy Act, Congress clarified that hydraulic fracturing was not to be included in the list of regulated underground injection activities. Consequently, fracking remains regulated under a variety of state statutes and regulations—a situation that concurrently allows for the consideration of region-specific geologic conditions, as well as differing priorities when balancing economic and environmental considerations, and also results in a patchwork of widely divergent regulatory practices.

Figure 6. Federal and State Regulatory Authority of Hydraulic Fracturing (using Colorado as an example)



Notwithstanding the different stringencies in state-level regulatory requirements, virtually all natural gas producing states have some regulations in place that govern specific operations and processes, including: cementing standards, tanks, storage pits, and reporting/mandatory actions to be taken in the event of a spill. Of the 33 significant natural gas producing states, 8 have specific regulations that pertain to “treatment, stimulation, and fracturing,” though not all are equally robust or stringent.

A May 2009 report conducted by the Ground Water Protection Council on the 27 states that produce 99.9 percent of all U.S. natural gas found that 78 percent of states required cement set-up periods or tests; 67 percent required production casing cement heights; 89 percent required production casing; 96 percent required surface casing cementing bottom to top; and 93 percent required surface casing below the deepest groundwater.²⁴

Hydraulic Fracturing Fluid

The hydraulic fracturing process requires large amounts of water, typically 1 million to 3 million gallons per well, to function properly (although in comparison to water usage for other energy technologies from nuclear to biodiesel, the volume is small in terms of gallons used per MMBTU of energy produced). In addition to water, fracking requires approximately 0.5 million pounds of sand and several tens of thousands of gallons of hydraulic fracturing fluids per well. On a percentage basis, fracking fluids comprise a very small amount of the overall volume of solution (less than 0.5 percent), and while some of the additives are also present in foodstuffs (e.g., guar gum, a thickener used in ice-cream and baked goods), others in undiluted form can pose a threat to human, animal, and plant safety. Companies are currently in the process of attempting to replace these components with “greener” and safer additives.

Current State of Fracking Fluid Regulation in the United States

A 2004 EPA study on hydraulic fracturing of coal bed methane deposits found that “the injection of hydraulic fracturing fluids into CBM wells poses minimal threat to USDWs [underwater sources of drinking water].”²⁵ This finding was instrumental in allowing fracking to remain unregulated at the federal level. In the absence of harmonized state regulation or federal requirements mandating a standard form of disclosure, the composition of fracking fluid has been subject to varying levels of disclosure. In recognition of the need to assuage fears on the part of land owners, industry actors are increasingly disposed to supporting more complete and clear

²⁴ Ground Water Protection Council, *State Oil and Natural Gas Regulations Designed to Protect Water Resources* (Oklahoma City, Okla.: Ground Water Protection Council, May 2009), <http://www.gwpc.org/e-library/documents/general/State%20Oil%20and%20Gas%20Regulations%20Designed%20to%20Protect%20Water%20Resources.pdf>.

²⁵ U.S. Environmental Protection Agency, “Evaluation of Impacts to Underground Sources of Drinking Water by Hydraulic Fracturing of Coalbed Methane Reservoirs,” fact sheet, June 2004, http://www.epa.gov/ogwdw000/uic/pdfs/cbmstudy_attach_uic_final_fact_sheet.pdf.

disclosure of constituent components of the various frack compounds, including publication of the constituent mixtures on their Web sites. In addition, the chemical constituents are also currently available on material safety data sheet (MSDS) submissions to local regulators. At issue, however, is the “granularity” of the constituent identification and the protection of “proprietary” mixtures.

Environmental Challenges and Threats

In part as a result of a renewed environmental awareness and in part due to the increasing number of wells being drilled in areas previously insulated from large-scale energy development efforts, from a public policy perspective there are a number of immediate and significant issues that need to be addressed in order for the development of unconventional shale gas resources to be realized. These include the following.

- *Surface water contamination*—resulting from leakage or overflow from surface containment ponds, and surface spills of frack fluids, resulting from improperly sealed valves, leaking tanks, ruptured lines, and/or human error.
- *Aquifer contamination*—most frequently caused by improper cement jobs or inadequate casing. Sediment disturbances that at least temporarily result in increased turbidity or lower water quality have also been attributed to drilling activity generally, but also have a variety of other potential natural causes.
- *Water use at scale*—the hydraulic fracturing process necessarily requires large amounts of water for it to work effectively. While technological advances have somewhat diminished the water requirements (e.g., through compressed air fracks and improved recycling and reuse of frack water), significant resources are still required to bring a single well into production. In many portions of the country, this water demand can be met by existing supplies (creeks, rivers, lakes, and discharge water from wastewater treatment plants) without causing significant deleterious environmental impacts. There are regions of the country, however, where hydraulic fracturing may be unsuitable due to the stress that increased drilling can place on a watershed. Given the water use at scale (both input and output), improved regional water management systems, as well as enhanced recycling, would appear to be prime candidates for government-industry collaboration.
- *Disposal of produced water*—the large volumes of brine and other constituent materials that emerge from the well along with the natural gas need to be treated and properly disposed of. In some cases, quantities of naturally occurring radioactive materials (NORM) are produced from the well. Typically, these materials can be reinjected into permitted Class II injection wells, but in some cases, these well sites are not proximate to the producing areas, thereby requiring tanker truckloads of fluids to be transported longer distances.
- *Natural gas leaks* (fugitive emissions)—on a lifecycle basis, the presence of methane gas leaks attendant to drilling and production operations partially offsets the GHG benefits derived from increased use of natural gas as a cleaner fuel. Given the value, producers are already

inclined to minimize loss and leakage, and many contracts and leases carry penalties for waste. It should also be noted that some aquifers contain naturally occurring biogenic gas traces unrelated to gas production activity.

- *Air pollution*—the sheer number of drilling rigs that have proliferated since the beginning of the shale gas boom pose a threat to ambient air quality standards through the emission of volatile organic compounds, nitrogen oxides, and particulates of varying sizes.
- *Surface disruptions*—ranging from noise pollution to increased congestion due to increases in vehicle traffic associated with the drilling activity. Unconventional natural gas production requires that large amounts of drilling/production materials be transported to the drilling site. This increase in vehicle traffic leads to greater wear and tear on existing roads, increased vehicle emissions, and added congestion on roadways. The use of remote monitoring and telemetry systems has been shown to reduce the amount of vehicle visits necessary to operate a well once it is under production, although there are obvious limitations on improvements in this area. Consolidating drill work with multiple wells drilled off a single drill pad has proved helpful in minimizing the production “footprint.”
- *Noise pollution*—gas drilling is a noisy process. The use of large compressors and other drilling equipment in addition to increased vehicle traffic are frequently cited by area inhabitants as disruptive activity. In more densely populated areas, sound walls and barriers have been used to minimize these disturbances, though their adoption in less populated areas remains minimal. Drillers frequently point out that the noise and disruption is limited to several weeks (mostly at the beginning of the drilling process), while the productive well life of the formations can last for decades.

The Upsurge in Alleged Water Contamination and Other Safety Incidents Associated with Hydraulic Fracturing

Not surprisingly, the burgeoning exploration and production of natural gas from unconventional sources has resulted in an increasing number of reports of water contamination and other safety issues. In response, the natural gas industry has frequently cited the results of the 2004 EPA study on hydraulic fracturing in coal bed methane deposits. The claim that “no documented” case of contamination exists with respect to hydraulic fracking activity may well be true, but likely only in the context of the fracking process carried out at target depth within the formation. There is an increasing body of empiric and anecdotal evidence that ties instances of water contamination and other health risks to the practice of hydraulic fracturing writ large, including improper surface handling of materials and accidents or unplanned problems with surface wells, casing, cement, storage tanks and equipment, and holding ponds.

In many cases, the concerns surrounding these contamination events can be addressed through enhanced standards, better regulation and enforcement, improved well design and operational “best practices,” including the handling of surface materials. In addition, industry should be disposed to better and more publicly disclose the constituent materials involved in the fracking

fluid mixtures, recognizing the limits of advancing a “generic” formula, while still preserving some flexibility to adjust the formulations for a formation-specific frack job.

Recommended Actions

Recognizing the enormous potential security, economic, and climate benefits for both the United States and the global community associated with the prudent and environmentally safe development/exploitation of unconventional gas resources, the U.S. government should encourage such development by undertaking the following actions.

Improve Information, Outreach, and Policy Framework

1. Task the U.S. Geological Survey to enhance its resource assessment methodology/capability to better determine the extent of recoverable U.S. and global resources.
2. Work with state governments to assess local/regional infrastructure needs necessary to support gas development and delivery, including roads, pipelines, waste water treatment facilities, etc. Given the significant volumes of water both injected as part of the fracking process and produced, explore regional water management schemes to encourage recycling of reduced disposed volumes by better regional integration of water management across projects. Gas development technology can also be used to better understand regional and local hydrology.
3. As a matter of policy, work to ensure that the timelines for reduction of coal use align with gas supply projections so there are no supply source gaps, as forecasts for gas usage are projected to increase. This is not a suggestion for government mandates, as market incentives can effectively move to fill such gaps, but rather a cautionary note against “overpromising” on where gas can make an economic and environmental contribution. Consider priority tiers for gas usage (e.g., fill un/underutilized gas capacity for power generation; retire old/dirtier coal facilities and replace with gas; consider focused transport uses—for instance, local and municipal fleets; etc.).
4. Encourage the international development of unconventional gas resources as a means for advancing climate objectives, as well as promoting regional economic and energy security objectives; promote U.S. companies and technology/expertise in producing unconventional gas around the globe.
5. Ensure that investments are self-sustaining and track energy, economic, and environmental priorities; adopting a price on carbon, an energy-intensity standard, or broader clean fuel definitions that include natural gas are possible means for accomplishing this objective.
6. Continue to fund research on carbon capture and storage (CCS) but expand to include CCS for gas-based energy production.
7. Support the timely completion of the EPA study on the potential impacts of hydraulic fracturing on underground sources of drinking water, encourage the public disclosure of the

additive materials that comprise frack fluids, and make that disclosure accessible to the public (several states [e.g., Pennsylvania, Wyoming] are implementing or considering the adoption of disclosure programs now). This would better respond to public concerns associated with the injection of hydraulic fracturing fluids into the reservoir. Also, to further assuage local residents of fears of ground water contamination associated with the fracking process, companies should pre-test local water wells (proximate to fracking operations) to establish measurable baselines and, in some instances, consider drilling monitoring wells and/or installing monitoring devices in local water wells.

Partner with State Regulators and Industry to Foster Best Practices, Management, and Effective Enforcement of Environmental and Safety Requirements

8. Promote a collaborative government-industry effort to increase and expand research around prudent development and management of unconventional gas resources, including the development of operational “best practices”—both for resource extraction and the reduction of fugitive gas emissions (natural gas STAR program), as well as for water contamination prevention, including the development of environmentally benign fracking fluids, procedures and practices for containing and managing surface operations, water reduction and recycling techniques, disposal of produced water and (regional) management at scale, recognizing local availability and use requirements. Efforts by such groups as STRONGER,²⁶ a nonprofit, multi-stakeholder organization, should be encouraged.
9. Create a forum for government, industry, and affected stakeholders to discuss the level and types of regulatory, programmatic, and operational activities that should be brought to bear to ensure that gas exploration and production is commercially viable and environmentally benign; provide financial support to state regulatory agencies to enhance ongoing inspection and enforcement efforts related to the development of unconventional gas resources; convene, under White House auspices, a forum for sharing of state regulatory practices and solutions; pursue integration of regulatory and research approaches to ensure compatibility.
10. Review applicable policies regarding access, taxation, and regulations to ensure compatibility as much as practicable with optimal development plans.

Conclusion

The United States is currently at a crossroads regarding its energy policy. The current path is generally understood to be unsustainable, but beginning down a more sustainable path is a complex and difficult task. Renewable technologies offer the long-term promise of a carbon-free world, though the day when they fully supplant fossil fuel resources appears to be decades in the future. The expanded use of natural gas represents a near-term, readily available step toward a

²⁶ For more information, see <http://www.strongerinc.org/>.

more sustainable and lower carbon future. Its production and use are not without challenges, but if properly managed, the benefits gas offers are a clear improvement over the status quo.

Framing the issue of U.S. energy policy as a choice between carbon-free sources and everything else is a false dichotomy. Natural gas is a fossil fuel whose burning still emits carbon dioxide and nitrous oxides into the atmosphere, but it also offers a cost competitive and significantly improved environmental profile from the status quo. Natural gas use represents a most cost-efficient way to scale up renewable electricity production without jeopardizing the continuous electricity supply that the U.S. economy requires, although it is also clear that, in a lower-demand growth scenario, gas can compete against renewables.

The transformation to a cleaner and more sustainable energy future will be uneven and, at times, painful. Technology may yet prove to be capable of simultaneously solving security, economic, and environmental concerns, but unbridled optimism cannot masquerade as policy. Though an “imperfect” fuel choice, natural gas nonetheless represents a reliable and available bridge to a brighter and more secure future.

About the Authors

Frank Verrastro is senior vice president and director of the Energy and National Security Program at CSIS. He has extensive energy experience, having spent 30 years in energy policy and project management positions in the U.S. government and the private sector. His government service includes staff positions in the White House (energy policy and planning) and the Departments of Interior and Energy, including serving as deputy assistant secretary for international energy resources. In the private sector, he has served as director of refinery policy and crude oil planning for TOSCO and more recently as senior vice president for Pennzoil. Responsibilities at Pennzoil included government affairs, corporate planning, risk assessment, and international negotiations. In addition, he served on the company's Executive Management and Operating Committees, as well as the Environmental, Safety, and Health Leadership Council.

Verrastro holds a B.S. in biology/chemistry from Fairfield University and a master's degree from Harvard University, and he completed the executive management program at the Yale University Graduate School of Business and Management. He has been an adjunct professor at the Elliott School of International Affairs at the George Washington University and at the University of Maryland. He served as chair for the Geopolitics and Policy Task Groups for the 2007 National Petroleum Council report, *Hard Truths: Facing the Hard Truths about Energy*, and as a Task Force member for the 2006 Council on Foreign Relations report, *National Security Consequences of U.S. Oil Dependency*. He has authored a variety of papers on energy and security topics and currently serves on the Advisory Board for the National Renewable Fuels Laboratory (NREL) in Golden, Colorado, and as a member of the Council on Foreign Relations.

Conor Branch is a graduate student at the Fletcher School of Law and Diplomacy where he concentrates his studies on international environmental and energy policy. In addition to natural gas, he has done research on renewable power generation in the developing world, smart-growth development, and carbon mitigation strategies through land-use change. He received an undergraduate degree in political science from the Colorado College.

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