Report

Risk Governance Guidelines for Unconventional Gas Development

Abbreviations and acronyms

AC	Atlantic Council
ACC	American Coal Council
API	American Petroleum Institute
CBM	coal bed methane
CGES	Centre for Global Energy Studies
CNG	compressed natural gas
CO_2	carbon dioxide
DOE	(US) Department of Energy
EAI	(US) Energy Information Administration
EC	European Commission
EPA	(US) Environmental Protection Agency
ERA	environmental risk assessment
ERCB	Energy Resources Conservation Board
GHG	greenhouse gases
GWP	global warming potential
HAP	hazardous air pollutant
IEA	International Energy Agency
JRC	(EC) Joint Research Centre
LCA	life cycle assessment
LNG	liquefied natural gas
NIOSH	(US) National Institute for Occupation Safety and Health
NGOs	non-governmental organizations
NO_x	nitrogen oxides
NORM	naturally occurring radioactive material
NYSDEC	New York State Department of Environmental Conservation
OECD	Organisation for Economic Co-operation and Development
RAE	(UK) Royal Academy of Engineering
SCER	(Australia) Standing Council on Energy Resources
SO_x	sulfur oxides
SRI	Siena Research Institute
tcm	trillion cubic meters
TDS	total dissolved solids
UG	unconventional gas
UGD	unconventional gas development
VOCs	volatile organic compounds

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Preface

Based on concerns that unconventional gas development is both under-regulated in some jurisdictions and also over-regulated in other parts of the world, the IRGC offers a set of risk governance recommendations relating to the development of this resource. The goal is that by applying these recommended actions, risks to the environment, climate, economy or society will be significantly reduced while the benefits of utilizing this newly available resource will be strengthened.

This report was generated based on an expert workshop, held in November 2012, an extensive literature review and numerous conversations with experts in academia, scientific institutions, industry, regulatory authorities and policymakers. The aim of this report is to help experts, in various countries and context conditions, to design policies, regulatory frameworks and industrial strategies to maximize the benefits that unconventional gas development could promise while reducing the associated risks. It will be followed by a policy brief that focuses on providing policy recommendations.

Executive summary

Numerous countries throughout the world are exploring the potential promise of unconventional gas development (UGD) as a component of national energy policy. IRGC presumes that policymakers seek to maximize the overall well-being of society, taking into account the risks and benefits of UGD compared with the risks and benefits of alternative energy sources. The global interest in UGD has been stimulated by a rapid increase in shale gas development in North America over the past 15 years.

This policy brief defines UGD as the use of advanced methods of hydraulic fracturing, coupled with directional drilling (i.e. horizontal as well as vertical drilling) to access natural gas resources that were previously considered technically inaccessible or uneconomic to produce. While this brief focuses on UGD from shales, many of the brief's risk governance recommendations are also relevant to gas development from tight gas sands and coal seams.

UGD could potentially provide a variety of benefits. Specifically:

- Provide affordable energy to businesses and consumers in the industrial, residential and transportation sectors;
- Create direct and indirect employment and economic prosperity;
- Contribute to a country's energy security by lowering dependence on imported energy;
- Provide a basis for a new export industry, since many countries seek to import natural gas;
- Generate fewer greenhouse gas (GHG) emissions than coal and oil;
- Diminish damage to local environmental quality by replacing some uses of coal and oil with a cleaner alternative;
- Provide a backup energy source to solar and wind renewables; and
- Enhance the competitiveness of a country's manufacturing sector, especially subsectors (e.g. chemicals, steel, plastic and forest products) that use natural gas as a key input to production.

UGD also potentially poses a variety of risks. Possible threats to human health, safety and the environment are prominent concerns, especially if effective risk management practices are not implemented. Potential threats include:

- Degradation of local air quality and water resources;
- Consumption of potentially scarce water supplies;
- Habitat fragmentation and ecosystem damage;
- Community stress and economic instability;
- Induced seismic events;
- Exacerbation of global climate change by triggering more emissions of methane, which is a potent, climate-changing gas; and
- Slowing the rate of investment in more sustainable energy systems.

While there are a series of both known and inferred potential benefits as well as threats associated with the development of this resource, there also may exist other impacts, both positive or negative, that might occur in either the short and long term, which are not yet fully understood.

In this report, IRGC examines the risks and benefits of UGD and offers some risk governance recommendations to guide the deliberations of policymakers, regulators, investors and stakeholders involved in the public debate about UGD. The recommendations are based in part on IRGC's integrated approach to risk governance (IRGC, 2005) and IRGC's previous work on risk governance deficits (IRGC, 2009) and in part on the insights that IRGC has drawn from doing work on risk governance in other technology sectors such as bioenergy and regulation of carbon capture and storage (IRGC, 2008a, 2008b). More importantly, the recommendations are based on a November 2012 international workshop, a review of the publicly available literature and case studies of recent political and regulatory developments concerning UGD in North America, Europe and Asia.

The IRGC definition of risk is an uncertain (usually adverse) consequence of an event or activity with regard to something that humans value. In the case of UGD, ineffective risk governance may lead to unnecessary environmental damage, foregone commercial opportunities, inefficient regulations, loss of public trust, inequitable distribution of risks and benefits, poor risk prioritization and failure to implement effective risk management. IRGC thus advises

decision-makers to consider the risk governance recommendations in this report as policy options concerning UGD are explored.

Risk governance recommendations for UGD

1. Countries considering UGD should establish estimates of their technically and economically recoverable gas reserves and revise such estimates over time.

2. The role of UGD in a country's national energy policy needs to be clarified by weighing the multiple risks and benefits of alternative energy sources through a process that encourages participation by a broad range of stakeholders and the public.

3. Policies to expand UGD should be implemented in ways that are consistent with global and national environmental goals (e.g. climate protection policies designed to slow the pace of climate change).

4. If a country envisions a major commitment to UGD, government and industry should expect to make a sustained investment in the associated capabilities (e.g. workforce, technology, infrastructure and communications) that are required for success.

5. A regulatory system to effectively govern UGD, including necessary permitting fees to support required regulatory activities, should be established, with meticulous attention to the principles of sound science, data quality, transparency and opportunity for local community and stakeholder participation.

6. Baseline conditions of some critical metrics should be measured and monitored to detect any adverse changes (e.g. changes to water supply and quality) resulting from development and these data are considered in the context of natural changes, along with the range of potential sources and mechanisms.

7. Since effective risk management at sites is feasible, companies engaged in UGD should adhere to best industry practices and strive to develop a strong safety culture, which includes sustained commitment to worker safety, community health and environmental protection.

8. During exploration, development and well closure, natural resources should be used efficiently; air and water quality should be protected; ecological harms should be minimized; and temporary disturbances of land should be remediated with care.

Major process recommendation

In undertaking this project, IRGC engaged in hundreds of UGD-related conversations with representatives from industry, local and national governments, international agencies, think tanks and other non-governmental organizations (NGOs). Based on these conversations, IRGC found that many officials around the world seek a better understanding – beyond the content of mass media reports – of the facts about UGD, including innovations in technical practices, regulatory systems and community engagement.

Therefore, IRGC makes the following process recommendation:

An international platform on UGD should be established through which interested stakeholders meet on a regular basis, share knowledge about technical practices, regulatory systems and community relationships, and help stimulate continuous improvement. Although this recommendation is straightforward, it is crucial because practices in the UG industry are maturing rapidly and many of the existing regulatory systems to oversee UGD are undergoing refinement or major reform.

In making this recommendation, IRGC underscores that the success of UGD will not be determined solely by engineering, geological and economic considerations. Without political legitimacy and local community cooperation, UGD is not sustainable. The challenge for national and community leaders is to determine whether development of an unconventional gas industry is in the interest of their constituents and, if so, what type of governance systems should be instituted to ensure proper risk assessment and management. In order to make informed decisions, national and community leaders, as well as investors and companies engaged in UGD, need prompt access to the best available information about technical, regulatory and community practices. The recommended international platform is intended to help meet this need.

Section 1:

Global interest in unconventional gas development

A "natural gas revolution" in the energy sector is under way. It is being driven by the large-scale development of natural gas from "unconventional reservoirs," which are dominated by shale formations, but also include tight sandstones and coal seams. In North America, the growing rate of gas production from these unconventional sources is already affecting global energy markets, international trade and energy prices. If the revolution carries forward to other countries, it will have wide-ranging implications for the future energy security of nation states and regions, and could be a significant factor in global efforts to reduce climate change.

Although much of the unconventional gas development to date has taken place in North America, companies and policymakers around the world are rapidly gaining interest in the future of UGD. In 2011, the International Energy Agency (IEA) released a report, *Are We Entering a Golden Age of Gas?* (IEA, 2011) and in 2012, it released *Golden Rules for Golden Age* (IEA, 2012c), indicating optimism about recoverable reserves, technology, extraction and production of unconventional gas. IEA foresees a tripling in the supply of unconventional gas between 2010 and 2035, leading to a much slower price increase than would otherwise be expected with rising global demand for natural gas. Global gas production could increase by 50% between 2010 and 2035, with unconventional sources supplying two thirds of the growth – a large percentage of which is likely to come from North America (from the United States in particular) (IEA, 2012b). The United Kingdom's Royal Society (Royal Society, 2012; UK, 2012), Resources for the Future (Brown & Krupnick, 2010), the US Energy Information Administration (EIA, 2011), the European Union (EC, 2011; 2012), Chatham House (Stevens, 2010), Econometrix (Econometrix, 2012), KPMG (2012) and Oliver Wyman (2013), among others, have recently released reports on UGD, with insights on development trends, technology, economics, risks, regulations and geopolitical ramifications.

What is clear from recent reports is that the growth of the unconventional gas industry is already having a profound impact in North America. The proportion of shale gas rose from less than 1% of domestic gas production in the United States in 2000 to more than 20% by 2010, and the EIA projects that it will account for 46% of the United States gas supply by 2035 (Stevens, 2012). Rapid growth in UGD has contributed to an 80% decline in natural gas prices in North America over the past decade. Lower energy costs, royalties paid to property owners and a growing workforce tied to the UG industry have stimulated the US economy. Of special note is a predicted revival of the North American manufacturing industry, especially natural gas-intensive manufacturing, such as petrochemicals, steel and paper (Tullo, 2012; ACC, 2013). Some European manufacturing firms are building new plants in the US instead of in Europe to capitalize on low-cost shale gas supplies (Hovland, 2013; Bryant, 2013; Chazan, 2013). Greenhouse gas emissions in the US have also been significantly reduced in the past five years, aided in large part by the substitution of coal for natural gas in power generation. Increasing use of natural gas as a transportation fuel is now widely proposed in North America, and new investments in vehicle technology and infrastructure are starting to be made.

Recoverable UG reserves: how much and where?

Unconventional gas itself is usually characterized as one of the following:

- **Shale gas**: Gas within shale is found in low-permeability, clay-rich sedimentary rocks. The shale is both the source and the reservoir for the natural gas. This occurs as both "free gas" trapped in the pores and fissures of the shale or adsorbed onto the organic matter contained in the matrix of the rocks.

- **Tight gas sands**: Tight gas systems are low-permeability reservoirs, usually comprised of sandstone, siltstones (tight sands), and limestones that serve as both the source and reservoir for the gas.

- **Coal bed methane (CBM)**: Coal bed methane is produced from and stored in coal seams. Coals have very high gas storage, as gas is adsorbed onto the organic matter in the coals and held in place by water. Production of the gas is achieved by de-watering the coal, allowing for desorption of the gas.

- **Methane hydrates**: These are a crystalline combination of natural gas and water formed at low temperatures under high pressure in the permafrost and under the ocean. These have not yet been developed and may not be commercially viable for at least another 10 to 20 years (CGES, 2010). However, a recent demonstration project in Japan resulted in a more optimistic timeline of five years.

This report deals only with the first three as they are onshore resources that are characterized by low permeability systems that require advanced drilling and completion technologies. There are many ways to estimate and report the potential resource base from one or all of these sources. Estimates of technically and economically recoverable reserves may be the most valuable numbers for policymakers, as they describe how much gas is available for production with current technology and prices. In undeveloped basins these estimates tend to be highly uncertain. Over time, such estimates are refined as detailed information is obtained from exploration and development efforts.

The EIA has published estimates of technically and economically recoverable gas resources (EIA, 2013b). For unconventional shale gas, it estimates that China has the world's largest reserves (33 trillion cubic meters or tcm), followed by Argentina (24 tcm), Algeria (21 tcm), United States (20 tcm), Canada (17 tcm), Mexico (15 tcm) and Australia (13 tcm) (EIA, 2013b). Other countries with potentially large reserves include Brazil, Russia, South Africa and, to a lesser extent, India and Pakistan. Shale gas is the major component of this unconventional reserve base in most cases, and Europe[1] as a whole has 18 tcm of technically recoverable resources, with Poland, France and Norway having the largest reported resources. The distribution of unconventional gas resources is global as shown in Figure 1. This is in contrast to the overall global natural gas resource distribution in which Russia is dominant followed by the United States (Figure 2).

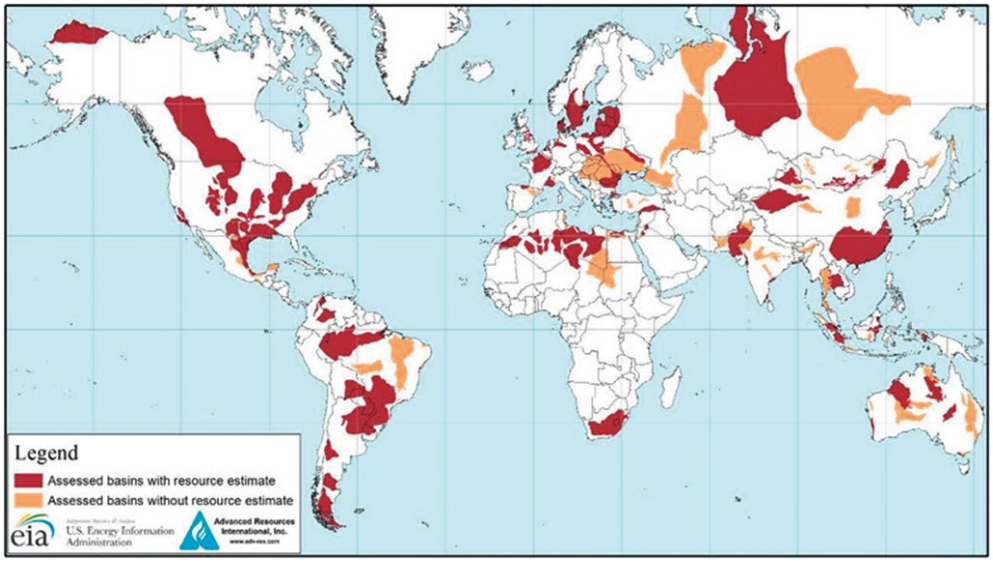


Figure 1. Assessed shale gas and shale oil basins in the world.

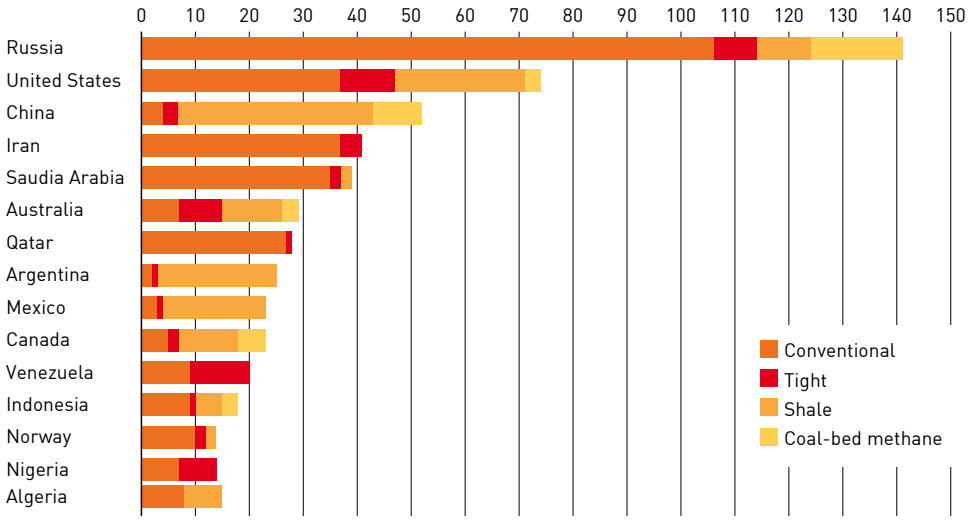


Figure 2. Recoverable natural gas reserves in trillion cubic meters (tcm) in 2011. Based on IEA

[1] Estimates for "Europe" includes the sum of resources from Bulgaria, Denmark, France, Germany, Hungary, Lithuania, the Netherlands, Norway, Poland, Romania, Sweden, Turkey, Ukraine and the United Kingdom.

The drivers of UGD

Rising global interest in UGD is driven by several factors:

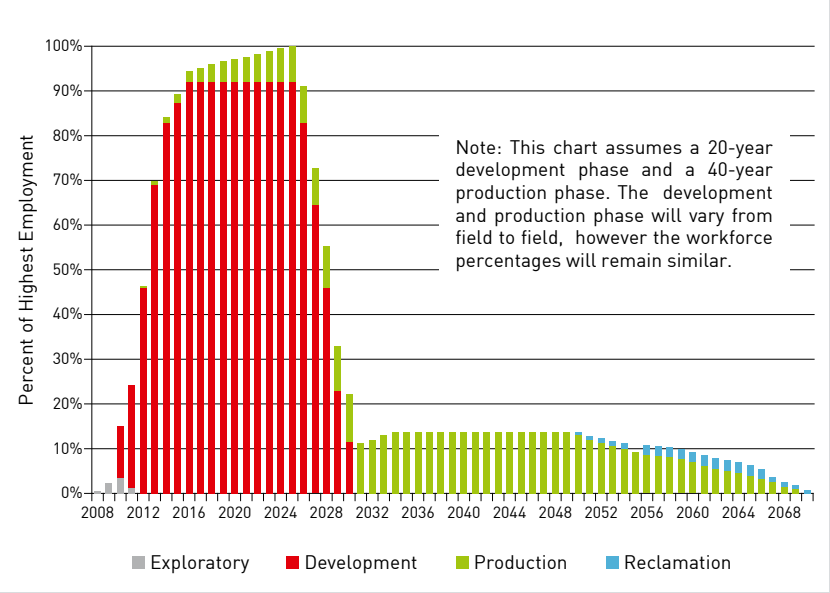
Successful research, development and demonstration

Modern methods of UGD represent a success story in research and development supported by industry and government. For example, the pioneer of advanced hydraulic fracturing is the late George P. Mitchell, a petroleum engineer and co-founder of Mitchell Energy and Development Group (US). Mitchell and his colleagues, using private funds and public support from the US Department of Energy, began extensive experiments in the late 1970s on the use of additives and staged stimulations. Over a period of 20 years, creative ways were developed to fracture shales and other unconventional reservoirs using staged slickwater hydraulic stimulations. Devon Energy Corporation bought Mitchell's firm in 2002 for US$3.1 billion, added innovative techniques of horizontal drilling and helped launch a surge in North American gas production (Fowler, 2013). More recently, petroleum engineers have implemented new methods to extract significantly more gas from each well than was possible even a year or two ago (Gold, 2013b).

Economic imperatives

The rapid, 15-year expansion in UGD within Canada and the United States reflects a variety of economic imperatives: the pursuit of profit by innovative energy service providers making use of advanced extraction technologies, the desire of communities and property owners for the financial rewards from localized economic development and royalty revenue, the creation of new employment opportunities (albeit in some cases hazardous to workers) (see Box 1) and the desire of consumers (residential, commercial and industrial) for a promising source of affordable energy (BCG, 2012). Additionally, Canada and the US, as market-oriented countries, view energy production as a promising source of prosperity and wealth, and are striving to gain a competitive edge in the huge global market for energy (ACC, 2012; BBC, 2012). But as a consequence of this rapid expansion in gas supply, the price of natural gas within Canada and the US is now quite low. And as a consequence there are a number of proposals in North America for new liquefied natural gas (LNG) terminals to export gas to Europe, Asia and elsewhere in the world where prices remains significantly higher.

Box 1: Job creation and occupational hazards



Job creation can be one of the primary benefits associated with unconventional gas development. A variety of technical and non-technical skills are required in each of the phases of development and, in general, workers in this industry are well compensated. The demands for highly educated and specialized personnel are greatest for conducting exploration activities. Lower-skilled labor is in the greatest demand to conduct development activities, such as well construction, drilling and hydraulic fracturing. As development activity subsides, the necessary workforce will shrink dramatically (Jacquet, 2009).

Figure 3. Projected employment patterns, percent of highest employment, for each of the stages of development of a hypothetical shale gas development. Source: Jacquet, 2009.

The pay received by workers in this industry can be attributed to the strenuous and often inflexible work schedules, and also reflects the occupational risks associated with working in the field. Workers are responsible for operating heavy equipment in close quarters and moving materials with the assistance of human labor (e.g. connecting drill string). Workers also have to handle chemicals. The death rate in the oil and gas industry (27.5 per 100,000 workers 2003–2009) is the highest of all US industries. The biggest contributor to this rate is transportation-related death (29%), followed by being struck by objects (20%), explosions (8%), being crushed by moving machinery (7%) and falls (6%). The estimated rate of non-fatal work-related injuries in 2010 was 1.2 per 100 full-time workers. National Institute for Occupation Safety and Health data suggest safety risks are elevated for new workers and smaller companies (NIOSH, 2012).

Declining conventional gas production

While Organisation for Economic Co-operation and Development (OECD) countries account for almost 50% of total natural gas consumption, production of conventional oil and gas has not kept pace. In the United States, the annual production of conventional gas has generally declined since production peaked in the early 1970s (USGS, n.d.). Declining production in the United Kingdom has also caused a downward trend in European output in recent years (IEA, 2012c). When oil and gas are produced in tandem at conventional plays, it is the anticipated price of oil, rather than that of gas, that drives gas development decisions since the commercial returns from oil and natural gas liquids are much greater, especially in North America.

Movement away from nuclear energy after Fukushima

In the wake of Fukushima, Japan's nuclear disaster in 2011, a number of countries have taken the decision to phase out nuclear power plants (e.g. Germany as well as Japan). Renewable energy is part of the energy portfolio, but so is increased consumption of fossil fuels, especially natural gas (EC, 2012). Thus, it seems likely the push for nuclear phase-outs will – and already is – expanding interest in UGD (Püttgen, 2012).

Reduction in carbon emissions

Natural gas used in power generation can reduce carbon dioxide emissions by approximately half when compared with coal combustion[2]. Between 2006 and 2011, the total carbon emissions in the United States fell by 7.7%, and the switch from coal to natural gas as a fuel for base-load generation has played a key role in this decline (IEA, 2012a). The reduction in CO_2 emissions in the US due to the shale gas revolution is about twice as large as the impact of EU efforts under the Kyoto Protocol (Victor, 2013).

Other substitutions of natural gas, including as a transportation fuel to replace petroleum or diesel, may also reduce greenhouse gas emissions. Because natural gas is cleaner burning than coal, it is widely touted as the fuel that can potentially bridge the gap to a lower-carbon future. The carbon emission reduction advantages of UGD may be offset in the post-2020 period if gas slows the penetration of low-carbon sources of electric power (e.g. new nuclear power plants and renewables) (EMF, 2013).

Global geopolitical considerations

Another reason for the growing interest in unconventional oil and gas is simply global geopolitics. The US and China, two of the world's largest economies, are major net energy importers. Another major energy importer, Japan, is seeking new sources of energy. Increasing domestic sources of energy would not only boost these countries' net trade balance, but also make them less reliant on the Middle East, which continues to be politically unstable. Much of Europe – and Poland, in particular – relies greatly on Russia for its energy needs. Russia alone is earning US$42–60 billion per year selling gas into Europe (Victor, 2013). Therefore, UGD would be geopolitically advantageous to many European countries. More UGD could also potentially mitigate the high gas prices in European markets by increasing supply. Some of the largest conventional oil- and gas-producing countries (e.g. Venezuela, Saudi Arabia and Iran) are not estimated to possess large unconventional gas resources. The distribution of unconventional gas resources outside of traditional oil-exporting nations portends a geopolitical shift of power and influence. The prospect for energy-importing countries, such as China, Poland or the US, becoming net exporters of energy is quite attractive to politicians from energy, economic and national security perspectives. In the long run, the prominence of the Persian Gulf nations and Russia in global energy markets may decline, and new players, such as Australia, Argentina or even West Africa, may become far more influential on the world market based on their ability to export both gas and oil produced from unconventional reservoirs (Gorst, 2013).

Table 1: Total natural gas production and consumption in OECD countries for selected years (tcm)

OECD countries	1971	1973	1990	2007	2008	2009	2010	2011e
Production (tcm)	.807	.876	.881	1.122	1.155	1.145	1.177	1.205
Consumption (tcm)	.791	.867	1.031	1.541	1.557	1.513	1.598	1.593
% Production/consumption	102%	101%	85%	73%	74%	76%	74%	76%

[2] Assuming fugitive methane emissions during the production process are well controlled.

Recommendations

IRGC believes that, as more countries around the world consider UGD, and as North America refines its policies toward UGD, it is worthwhile for policymakers, industry and other stakeholders to consider some common risk governance guidelines to reduce the negative impacts associated with development and enhance the positive ones. In this report, IRGC suggests a set of risk governance recommendations that were guided by IRGC's multi-disciplinary approach to risk governance, its previous assessments of risk governance in other technology developments (e.g., bioenergy and carbon capture and storage) and, most importantly, the input received at a workshop on UGD held in November 2102. (See in Acknowledgements, for a list of the scientists, engineers, risk analysts, regulators and other practitioners who participated in the workshop.) Within this report, IRGC's general recommendations for effective governance of risk are presented, with recognition that each region or country may need to tailor the application of the guidelines to local conditions, cultures and political/legal traditions.

The key recommendations include:

1. Countries considering UGD should work to obtain accurate estimates of their technically and economically recoverable reserves of UG and revise such estimates over time.

   Countries considering UGD need to recognize that current available estimates of gas resources have a degree of fragility to them. In order to make informed decisions about national energy policy and UGD, countries should acquire the best available estimates of technically and economically recoverable reserves. Since estimates may change significantly due to detailed land surveys and initial exploratory drilling, and production experience, estimates of recoverable reserves should be updated periodically based on recent evidence.

2. The role of UGD in a country's national energy policy needs to be clarified by weighing the multiple risks and benefits of alternative energy sources through a process that encourages participation by a broad range of stakeholders and the public.

   Since the risk-benefit calculus will vary on a country-by-country basis, UGD will play a larger role in some countries than in others. A country's mix of energy sources is also expected to change over time due to a variety of technical, economic and policy factors. When considering UGD, countries should clarify how it will fit into their portfolio of energy sources and, particularly, how UGD will impact the degree of dependence on other fossil fuels, nuclear power and renewable sources. As a country's experience with UGD grows, policymakers' expectations should be updated, and the projected mix of energy sources for the future should be modified accordingly. As a key component of refining a nation's energy policies, opportunities for input from stakeholders and the public should be provided.

3. Countries should clarify how the development of their unconventional gas reserves will be implemented in a way that helps meet (or at least does not obstruct) the nation's climate-protection policies.

   If a growing UG industry is viewed as a threat to attainment of a country's climate-protection goals, opposition to UGD is expected to intensify. A country's UGD policy should address, in an analytic and transparent manner, how UGD will help meet the country's climate-protection goals, including any obligations under international treaties.

4. Countries envisioning a major commitment to UGD should allocate financial resources to develop the skills and capabilities to do it safely and sustainably.

   Government and industry should expect to make a sustained investment in the associated capabilities (e.g. workforce, technology, infrastructure and communications) that are required for success.

Section 2:

Identifying and managing risks

Introduction

Like all sources of energy, unconventional gas production is not without risk. Throughout the entire process of gas production and use, there are potential risks to human health, safety and the environment. In this section we identify the major risks and suggest how these risks can be managed from a technical perspective.

The section begins with a basic description of the steps in a UGD project. The risks are then examined as they relate to land, water and air resources. To ensure proper technical management of risk, governance recommendations are suggested for each resource category. The level of risk will vary from locality to locality and, therefore, no attempt has been made to prioritize these risks. Such prioritization should be an essential element of the risk governance in any given setting.

Phases of UGD

No two unconventional gas development projects will be the same, but the activities for commercial development can be segregated into four general phases: exploration, development, production and closure. The phases overlap in various ways, but are frequently discussed separately within the industry.

Exploration

In the exploration phase, the primary goal is to discover the gas resources, assess their accessibility and magnitude, and determine their commercial promise/technical recoverability. Exploration activities include the collection and analysis of geological and geophysical data, along with the drilling of exploratory wells with limited testing (and hydraulic fracturing) to gauge rates of production. In some cases, wildcat wells are drilled outside known oil/gas basins, despite the higher financial and technical risks. Exploration and/or development (sometimes mineral) rights often provide the legal basis to conduct these activities. These rights are contractually secured, but the process for acquiring them can take many forms depending on the existing legal structures and government policies of a given nation (e.g. contracts with private owners of mineral rights versus public auctions of promising tracts when land/mineral rights are publicly owned).

A gas developer will require some subsurface geological and geophysical information to guide the development process. Requisite data on reservoir characteristics, such as depth and thickness, can be obtained through reflection seismic surveys, which involve sending pulses of energy into the subsurface and then recording and correlating that energy's response to subsurface features. In a given development, several exploratory boreholes may be drilled. Pressure, density, temperature and gamma response data, along with borehole geometry information, are routinely collected as these wells are drilled and, in some cases, core samples will be collected for further laboratory analysis. Additional information may be obtained from formation outcrops and data collected during past conventional oil and gas developments. Proprietary software will then be used to synthesize this information with existing data and experience, and estimate the properties of the reservoir.

A significant amount of upfront planning also occurs in parallel to the exploration activities before further investment in commercial development. Existing regulations and policies, environmental concerns and other constraints to development need to be identified. Existing and future product and waste handling and processing capacities and needs will also be examined. Only after all of these factors and others have been considered can a realistic assessment of the economic potential of developing the resource be fully understood. For these reasons, acquisition of exploratory or development rights does not necessarily mean commercial UG production will occur.

Development

While exploration activities may cover a large geographical area, development typically concentrates on core areas where production economics are most favorable (known as "sweet spots"). Production-related facilities include well-site separation and storage equipment, pipelines, and compression and processing facilities. The infrastructure requirements, beyond establishment of production facilities, are significant, especially if a large number of wells are to be drilled and completed. Road and pipeline access to production sites need to be established, as materials, water and equipment must be transported to and from the multiple production sites. If the reservoir produces both natural gas and a liquid hydrocarbon component, larger and more extensive equipment will be required to extract, separate and transport the produced fluids. If the gas reservoir exists within the

bounds of a previously established oil- or gas-producing region, the additional facilities required could be significantly less.

Unconventional gas reservoirs are accessed by drilling wellbores vertically through the overlying bedrock. The wellbore may enter the reservoir vertically, but is then usually turned to move horizontally through the producing formation. With current onshore technology, the horizontal portion of the wellbore can be drilled thousands of meters from the vertical wellbore (King, H., 2012a; Helms, 2008). This is accomplished using a high-pressure drilling mud that delivers energy to a steerable "mud" motor in the drill bit that is set in angled and horizontal trajectories. Advancing technologies for down-hole measurement, data telemetry (Brommer, 2008; Helms, 2008) and subsurface modeling enable real-time control of drill-bit navigation and optimal placement of the wellbore in the reservoir (Halliburton, 2012).

Drilling operations may be suspended multiple times to insert steel casing (generally cemented) into the wellbore, which prevents the wellbore from collapsing and impairs fluid migration into or out of the well. When drilling reaches the depth of the reservoir, the wellbore may contain multiple "strings" of casing, which collectively act to isolate the hydrocarbon and brine-rich horizons from potable groundwater aquifers. The longest "string" of casing, known as the production casing, extends from the surface to the end of the drilled wellbore.

When the drilling and casing operations are finished, the process of stimulating the formation using hydraulic fracturing is undertaken (King, H., 2012b). Hydraulic fracturing is designed to enhance connectivity of the reservoir to the well and thereby promote the flow of gas into the production casing. It is usually performed in a series of "stages" over segments of the wellbore in the target reservoir. At each stage, a portion of the casing will be perforated (typically through oriented explosive charges) and then a sequence of fluids will be pumped into the perforated section at high pressure. The largest volumes of water (up to 20,000 m^3) and pressure are needed to induce fracturing of the surrounding rock and to carry "proppant" (sand or ceramic grains) deep into the fine cracks in the formation. For this sequence, pumping rates may exceed 12 m^3 per minute and down-hole pressures can rise to approximately 20,000 psi 1,400 bars (Montgomery & Smith, 2010). In successful hydraulic fracturing operations, the proppant will prevent closure of the induced fractures after pumping pressure is relieved. Modern hydraulic fracturing operations rely on a suite of chemicals to achieve the properties necessary to convey pressure and proppant to the fracture tips (GWPC, 2011).

Production

Production from unconventional reservoirs is established in the "flowback" period in which the water and excess proppant, which were used to stimulate the well, along with some of the fluid native to the formation, are allowed to flow out of the well. During this process, significant amounts of fluid, dissolved minerals and chemicals, and other entrained materials are flowed to the surface and collected. Once this initial high volume of fluid is produced, wells generally produce little water, which is often collected in tanks on the well pad. Throughout a well's life span, regular visits to the well site will be necessary to test gas pressure measurements, collect produced water for disposal and to perform site maintenance, such as repairing erosion and/or storm water controls, among other activities. Unconventional gas wells are characterized by high initial production that declines rapidly in the first few years to production levels that may be sustained for decades. Some closure activities will occur during the production phase when parts of the drilling pad are reclaimed as production is on-going. Also, gathering lines to collect the gas and send it on to a pipeline for sale and distribution are constructed. When the costs for operating a well exceed the value of the gas and liquid hydrocarbons produced, its operations will typically be suspended temporarily, but it will ultimately need to be decommissioned.

Closure

The process for decommissioning an unconventional well, known as plugging and abandonment, begins with the removal of the surface equipment and infrastructure for production of gas from the well. This includes the dehydrator, wellhead and tank batteries. The steel production casing, which extends from the surface to the producing formation may also be removed and sold as scrap. Finally, a series of cement plugs are constructed within the wellbore to isolate the various water and hydrocarbon-bearing formations from each other and the shallow groundwater system. The final stage in this reclamation process is rehabilitation of the well site to an alternative use.

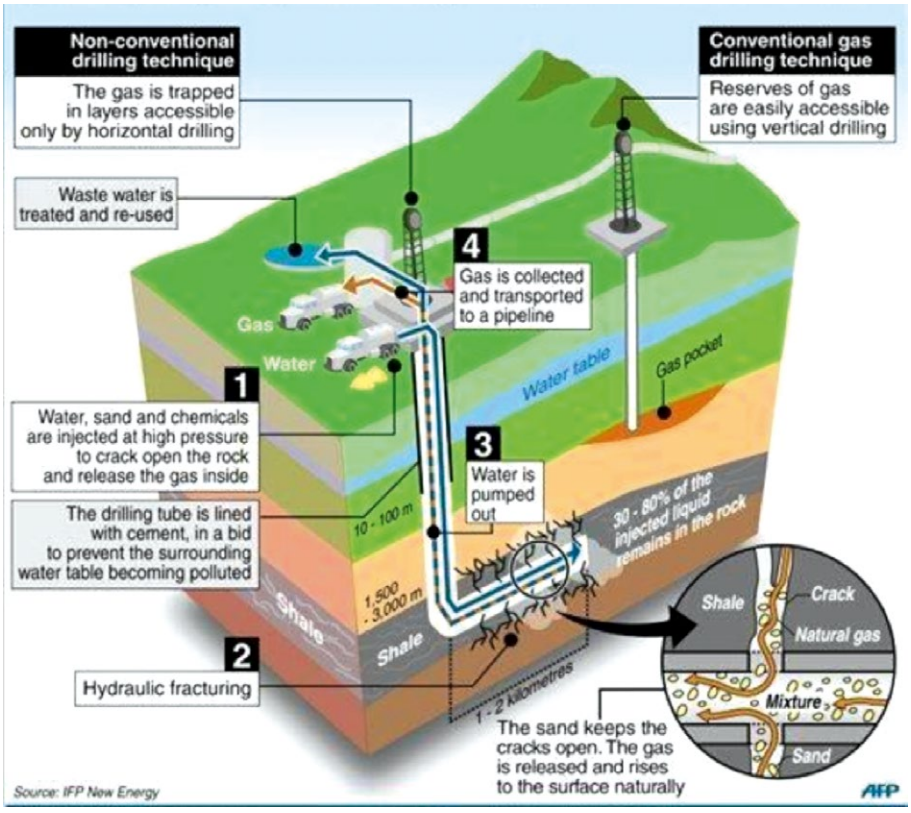


Figure 4. Basic dynamics of shale gas extraction in a horizontal well-bore. (Hydraulic fracturing can also be utilized to enhance reservoir performance in a conventional vertical well.) Source: IFP New Energy

Risk identification

From a business perspective, natural gas production from unconventional reservoirs poses a variety of financial risks. Such a capital-intensive enterprise proceeds without assurance or understanding of the extent of the potential payoff. The focus of this section, though, is not the financial risks, which market forces are designed to address, but the unintended risks to public health, safety and the environment that could possibly occur as a consequence of the gas development process. These risks may create damage to society that extends beyond the financial damage to businesses and property owners with commercial interests in UG development.

Unintended consequences can be categorized as those associated with the adequacy of engineering practices and technologies, and those associated with human operational factors, though sometimes technical and behavioral factors interact to accentuate risk. Risks can also be assessed by the severity of their harm (inconvenience to neighbors versus health damage from drinking water contamination), the temporal nature of the risk (immediate versus long-term cumulative risks) and spatial extent (localized effects versus those that extend over large geographical areas).

For clarity of discussion, risks are itemized below according to whether they impact land, water or air. Not all risks are of the same likelihood or severity of consequence, and thus relative risks need to be assessed on a site-by-site and region-by-region basis in order to give appropriate priority to risk management activities.

Land

As with all energy resource developments, the effect of UGD on the land can be significant, including impacts to both the current and potential land uses, and the associated ecological systems. The environmental risks depend on site-specific factors, such as the climate, topography and existing uses of the land, and on the pace and scale of development. Some of the impacts on land are similar to conventional gas development and other mining and industrial activities. However, because of the dispersed nature of this resource in the subsurface, the overall footprint or impact of unconventional gas development is generally larger than that of conventional gas development, which is concentrated in smaller areas (fields). This impact involves roads, pipeline right-of-ways, along with production and gathering facilities. Nonetheless, land impact from UGD is likely to be smaller than from other energy sources (NGSA, 2013). In a study by the American Petroleum Institute (SAIC/RW Beck, 2013), the number of acres of land needed to produce the fuel to power 1,000 homes for one year is: natural gas 0.4, coal 0.7, biomass 0.8, nuclear 0.7, wind 6, solar 8.4.

Land erosion and water siltation

A flat and stable well pad is needed for unconventional gas development, which requires the surface of the well pad to be graded and typically covered in crushed stone or gravel (NYSDEC, 2011). In some settings, this pad may also need to be impermeable (e.g. concrete) to prevent fluids from seeping into the subsurface. Access roads are required to link existing roadways to the well pad for access and egress of people, equipment and materials. Land is also cleared for gathering pipelines and infrastructure to process and distribute the produced gas. To summarize these activities, Johnson *et al.* (2010) estimated that about 12 ha are impacted by the establishment and support of a multi-well pad development.

Some of the impacts include:

- Changes to surface gradients and land biomass/soil compositions from UGD increase the risks of erosion and siltation of surface waters (Entrekin *et al.*, 2011).
- Loss of nutrient-rich topsoil can permanently impair use of land in the future (Drohan *et al.*, 2012).
- Physiographic changes associated with preparing the well pad may also affect groundwater recharge and surface runoff.
- Removal of vegetation will also change local evapotranspiration rates (Harbor, 2007).

Habitat loss and ecosystem fragmentation

Unconventional gas reservoirs exist below a variety of surface environments and the expected land use change from developing these resources is not equal. Habitat loss can be directly correlated to the amount of land required to develop unconventional gas reservoirs. However, impacts are not only measured in direct land disturbance, but also include "edge effects," – a well-known ecological concept in which adjacent lands, especially in forested areas, can be impacted by disturbance. The disturbance creates new edges within "interior ecosystems," which are inhospitable to sensitive flora and fauna (e.g. songbirds). The cumulative effects of multiple disturbances result in habitat fragmentation, which threatens native species while space is created for invasive species to thrive (Johnson *et al.*, 2010; Drohan *et al.*, 2012; Slonecker *et al.*, 2012).

The risks associated with land use change from UG operations are highest in sensitive areas and when steps are not taken to lessen the disturbance. Drohan *et al.* (2012) point out that a managed, organized approach to drilling and infrastructure could help minimize these impacts. However, the ecological impacts of land use change for UGD may take time to develop. This inhibits risk assessment and management, as siting restrictions can significantly alter production economics.

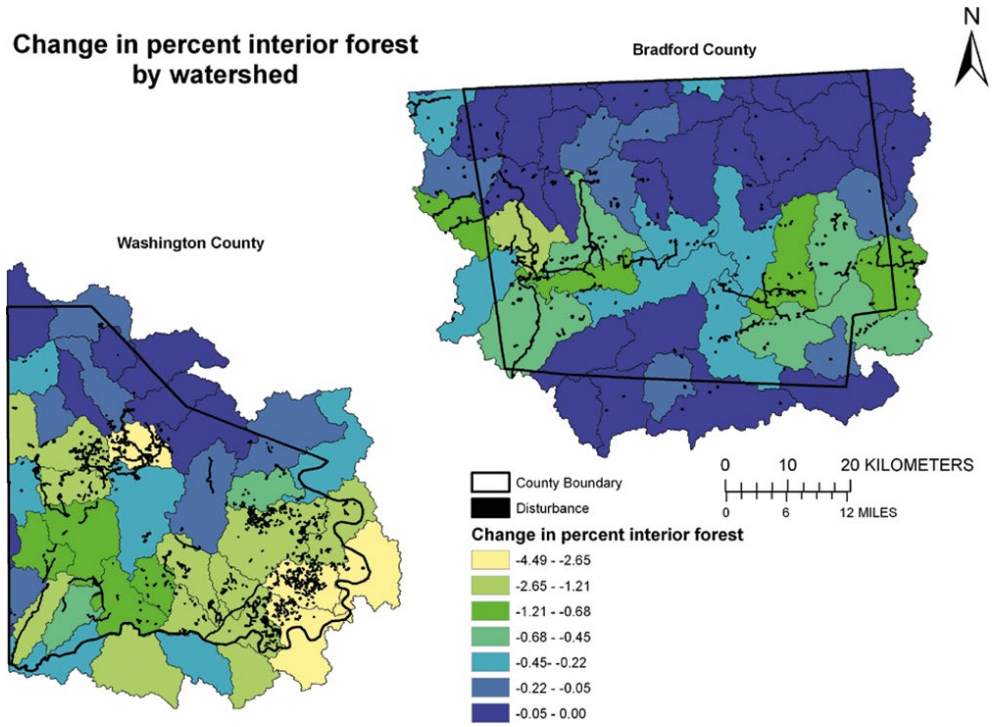


Figure 5. Change from all developments (due to UGD and other activities) in percent interior forest by watershed in Bradford and Washington counties, Pennsylvania, from 2001 to 2010. Source: Slonecker *et al.*, 2012.

Inadequate surface rehabilitation

Once drilling and hydraulic fracturing operations are complete on a particular well pad, the equipment and materials not needed to sustain production can be removed. A well pad area of less than one hectare is sufficient (NYSDEC, 2011). After all producing wells on a well pad are decommissioned, the remaining portion of the well pad and other surface disturbances maintained for servicing of the well will no longer be necessary, leaving only pipeline easements.

Due to soil compaction, removal of topsoil and the layer of gravel covering the well pad and access roads, natural recovery of the surface environment to its original state should not be expected. Soil conservation measures, such as the installation and maintenance of erosion controls and use of storm water management practices, may reduce damage to the surface environment. If the surface disturbances become permanent, the adverse impacts of habitat loss and ecosystem fragmentation are accentuated. Complete reclamation of the surface usually involves the removal of the gravel layer, land re-grading and replacement of topsoil, and re-vegetation. Minimizing the effects of UG development on habitats requires that reclamation activities are appropriate and timely.

Recommendations

1. Perform baseline measurements to assess ecosystem health (e.g. species abundance) and characterize existing habitats (e.g. aerial surveys); identify existing environmental pollution (e.g. erosion and sedimentation). Baseline measurements should be recorded prior to commercial UG development. Monitor changes in all phases of commercial development.

2. Include the risks associated with well pad development in siting decisions and construction operations. Use appropriate soil conservation measures and maintain environmental controls (e.g. erosion barriers) for as long as they are necessary.

3. Use land efficiently and consider opportunities to reduce the footprint of well pad and infrastructure development. This may include collaborative development (e.g. shared rights-of-way for pipelines) and organized development units.

4. Pre-plan intermediate and final surface reclamation and their costs. Plans should include all of the activities at the surface to restore the land to its natural or pre-development state.

Water

Multiple processes associated with extraction of unconventional gas pose risks to water resources. These risks can impact the availability and quality of surface and groundwater. The effects of these risks may vary according to natural factors, such as hydrology and geology, as well as on existing uses and demands for water resources and the manner in which the water is utilized. In gauging the impact to water resources, it is important to bear in mind the relative usage for UGD in comparison with other large consumers of water such as agriculture and thermal power sectors. Water usage is changing in many areas as new techniques to recycle and reuse both water used for stimulation and produced waters are being employed (Stark *et al.*, 2012; Nicot *et al.*, 2012; EID, 2013).

Water supply diminution

Water is used in dust suppression, drilling "mud" formulation and in the hydraulic fracturing process. The largest water demands are associated with hydraulic fracturing in shale formations, which requires 10,000–20,000 m^3 per well (DOE, 2009). Smaller amounts are needed for developing coal bed methane (DOE, 2004). Modes for transporting the water include tanker trucks or pipelines, and the water is typically taken from local sources due to the cost of water hauling (Arthur *et al.*, 2010). At or near the well pad, water for hydraulic fracturing may be stored in lined ponds (impoundments) or kept in mobile tanks (Arthur *et al.*, 2010).

There are risks of water supply diminution due to the consumptive use of freshwater for UGD, especially in regions where freshwater supplies are constrained. Aquatic, riparian and floodplain ecosystems are directly impacted by reductions in flow. Ecological responses to changes in habitat availability or disruptions to the life cycles of plant and animal species can be assessed (DePhilip & Moberg, 2010). Water withdrawals may also cause second-order impacts to water quality, such as changes in temperature. The principal risk of groundwater withdrawals is aquifer drawdown, which can negatively impact the use of water wells for drinking, agriculture and other purposes (Nicot & Scanlon, 2012).

The water demands for unconventional gas operations are not constant, but are usually concentrated when and where unconventional wells are being hydraulically fractured (Mitchell *et al.*, 2013). An assessment of local resource capacity is necessary to determine what effects freshwater demands for UGD may have. The assessment of local resource capacity should be complemented with a holistic characterization of the current and future water demands for hydraulic fracturing in the

context of existing uses of water resources, including ecological needs. Freshwater consumption may be reduced by the use of alternative water sources. These include recycling of water used in the hydraulic fracture stimulations "flowback" water (Lutz *et al.*, 2013), use of water produced with gas and acid mine drainage (Curtright & Giglio, 2012). In areas of limited water supply the risks are more widespread, so both local and accumulative impacts are likely.

Fluid migration outside of production casing

Drilling an unconventional gas well can potentially compromise the natural separation that isolates potable groundwater systems from deeper brine and hydrocarbon-bearing strata. To allow for the production of hydrocarbons and prevent movement of fluids into groundwater, the drilled borehole is cased (steel pipe cemented into the wellbore). Multiple layers of steel and cement may be used to isolate potable aquifers and provide protection of the groundwater resource.

Although the procedures and materials used in the casing process reflect decades of continually advancing technologies and often meet strict design criteria, successful isolation is obtained when appropriate implementation and verification measures are used. The seal created by the cement with the wellbore is the critical component, yet problems may arise, which could affect the quality of the seal (King, G., 2012). The presence of a flaw increases the risk of unintended pathways that connect groundwater with fluids from the deep subsurface, including with brine, hydrocarbons (particularly dissolved and free methane) and fracturing fluids. The most common problem with casing construction is poor bonding between the casing and cement or the cement and/or the borehole wall. The frequency of leaking casing problems in association with UGD is in the range of 1 to 3% (Vidic *et al.*, 2013).

The integrity of the casing/cement system must survive the repeated stresses associated with hydraulic fracturing and throughout its productive lifetime (King, G., 2012). Additionally, the system must also continue to isolate the various fluid-bearing strata in the subsurface after the well has ceased production and is plugged and abandoned. Wells are subject to mechanical, thermal and chemical stresses in the subsurface. Compromised integrity of the mechanical isolation may be due to degradation of the wellbore, corrosion in steel sections of casing or changing geological conditions (Det Norske Veritas, 2013). Complete verification of wellbore seal integrity is not possible. Pressure monitoring and tests to estimate the quality of the cement bond with the wellbore are commonly used. If problems are identified, "workovers," the industry term for repairing a well, are possible interventions to address these issues (King, H., 2012b).

When sites are selected carefully and fracking operations are conducted using state-of-the-art methods, groundwater chemistry in shallow aquifer systems should reflect only natural processes. This has been verified, for example, in a study of shallow groundwater quality in a shale-production area in Arkansas. From 2004 to 2012, about 4,000 producing wells were completed in the Fayetteville Shale (north-central Arkansas). Sampling of 127 domestic wells took place to assess water quality. The comparisons to historical (pre-production) values and to water-quality values in neighboring areas (without gas production) showed no evidence of degradation of water quality (Kresse *et al.*, 2012).

A recent study of methane contamination of drinking water supplies in Pennsylvania found that methane concentrations in drinking water are elevated in wells near oil and gas operations. The authors advance several possible pathways that could explain the contamination but suggest that the pattern of contamination is more consistent with leaky gas-well casings than with release and long-distance migration of methane after hydraulic fracturing (Osborn *et al.*, 2011; Warner *et al.*, 2012). Additional challenges and complexities associated with the potential for groundwater contamination are being investigated by the USEPA, the state of NY Department of Health and other entities in various states. Several comprehensive reports are expected from these sources in the near future.

Implementation of best industry practices can minimize the risk of fluid migration from casings. The risks associated with poor well construction and isolation of groundwater supplies may be controlled if problems are identified and proper steps are taken to remediate problems.

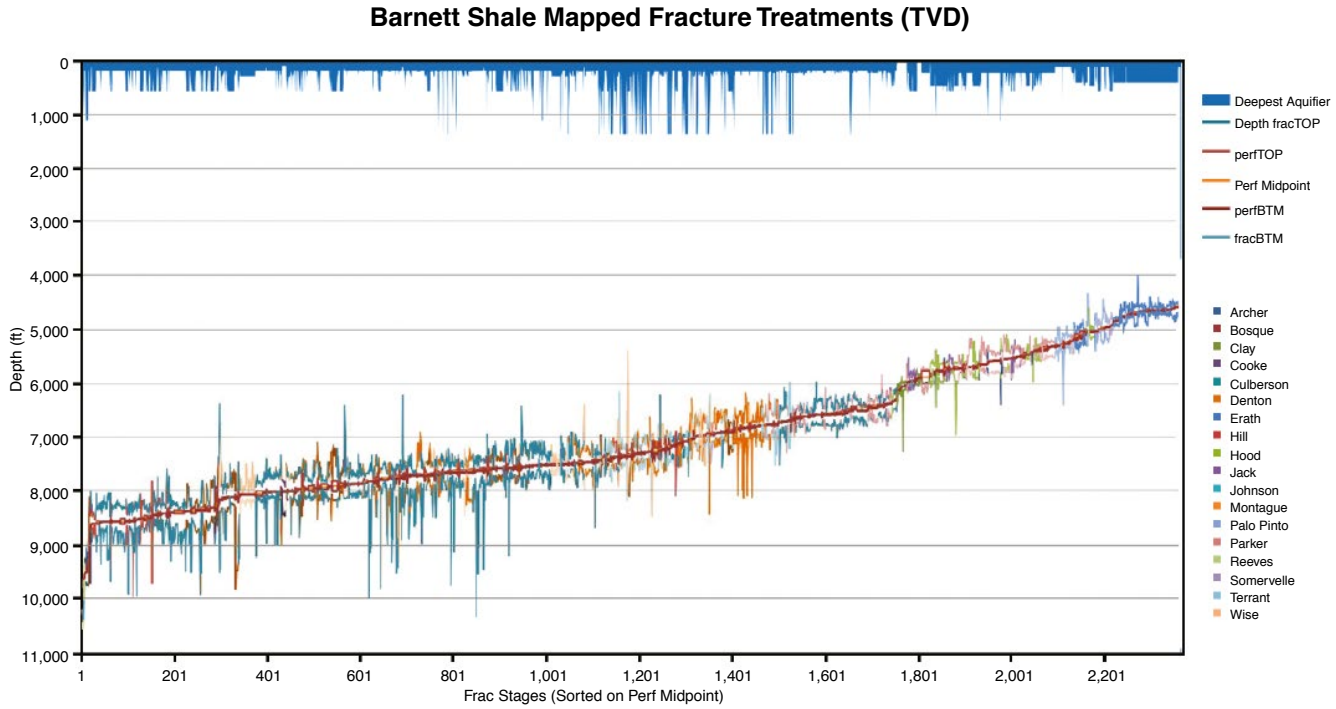
Fracture communication with groundwater

With hydraulic fracturing, the potential exists to hydraulically connect gas-producing reservoirs with water-bearing zones in the subsurface (including underground sources of drinking water). This risk of subsurface groundwater contamination from hydraulic fracturing is understood to be correlated with the depth at which fracturing occurs (King, H., 2012b). Increasing the vertical separation of the underground sources of drinking water with the producing horizons reduces the risk because there will be more confining layers of overlying rock (or "frac barriers") to limit fracture propagation upward (Davies *et al.*, 2012). No empirical data currently exist that conclusively demonstrate there has been direct communication of hydraulically stimulated producing horizons with groundwater reservoirs (EPA, 2004). In fact, a recent study used tracers at a site in Greene County, West Virginia to discern where fluids resided after fracking operations. After a year of monitoring, the study found that the fluids remained isolated from the shallower areas that supply drinking water (AP, 2013, Hammack *et al.*, 2013). However, it may be too early to say the risk is zero, as it may take an extended period of time for these unintended consequences to develop or be detected. One concern is that the groundwater and the underlying reservoirs could have pre-existing (natural) hydraulic connections (Warner *et al.*, 2012). Currently, the US Environmental Protection Agency is engaged in assessment of "The Potential Impacts of Hydraulic Fracturing on Drinking Water Resources," with the final results expected to be released in 2014. In the EU, the impact of hydraulic stimulation was initially investigated in Poland in 2011 and did not show any changes in the natural environment which could be linked with the hydraulic fracturing (Konieczynska *et al.*, 2011)

Uncertainty about this risk is elevated by a poor understanding of subsurface fluid flow and the existence of subsurface geological features (IEA, 2012c). Encountering a natural fracture that leads to potable water supplies is possible, but there is incentive for drillers to avoid intersecting these features because they can negatively impact desirable fracture propagation, and subsequently, gas production (Gale *et al.*, 2007). Because fluids are being introduced at high rates and pressures, there are additional risks of subsurface communication in areas with a history of oil and gas drilling or underground mining due to the weakness in the overlying rocks that these activities have created. There also exists the risk that fractures formed by a hydraulic stimulation could intersect a pre-existing wellbore that also intersects the reservoir being stimulated. The induced fractures could compromise the integrity of this wellbore and possibly lead to the migration of fluids out of the producing zone and into overlying horizons. The presence of these conditions reduces the pressure required to push the fluids in the reservoir up thousands of feet. Hydraulic fracture monitoring (see Figure 6) allows for three-dimensional modeling of fracture propagation, though these technologies may not be suitable in all circumstances and can be prohibitively expensive (Neal, 2010). These figures show the estimated distance between the deepest surface aquifers and the height and location of the fractures induced by the stimulation of the reservoir.

A related yet tangential aspect of this potential risk is the long-term fate of the injected fluids. While they begin by residing only in the induced and natural fractures, only 50 to 70 percent of the introduced fluids return to the surface as flowback fluid. The balance of the fluid remains in the reservoir and has the potential to interact chemically with native fluids and the reservoir rock. Some chemical agents, specifically metals and organic compounds, may be mobilized and could migrate over time into the fracture system and even out of the reservoir. As the development of shale gas reservoirs is a relatively new technology, this possible long-term risk has yet to be fully assessed and evaluated (Portier *et al.*, 2007).

In addition to the risk of establishing direct hydrological communication between the hydrocarbon-bearing reservoir and the groundwater system, there exists the potential risk of large-scale perturbation of the subsurface hydrological flow regime due to extensive drilling and hydraulic stimulation. In many cases, the stratigraphic units that are being targeted for UGD are low permeability zones that serve as barriers to flow within the subsurface environment. Modification of this role on scales that may permit subsurface fluids and pressures to significantly change may have unforeseen consequences on other aspects of the subsurface hydrologic regime. As with the risk associated with the possible mobilization of chemicals and the long-term fate of introduced fluids, this potential risk has yet to be fully assessed and may have important consequences for development of some regions. Analogs have been modeled in relation to large-scale hydrological effects of geological sequestration (Tsang *et al.*, 2008).



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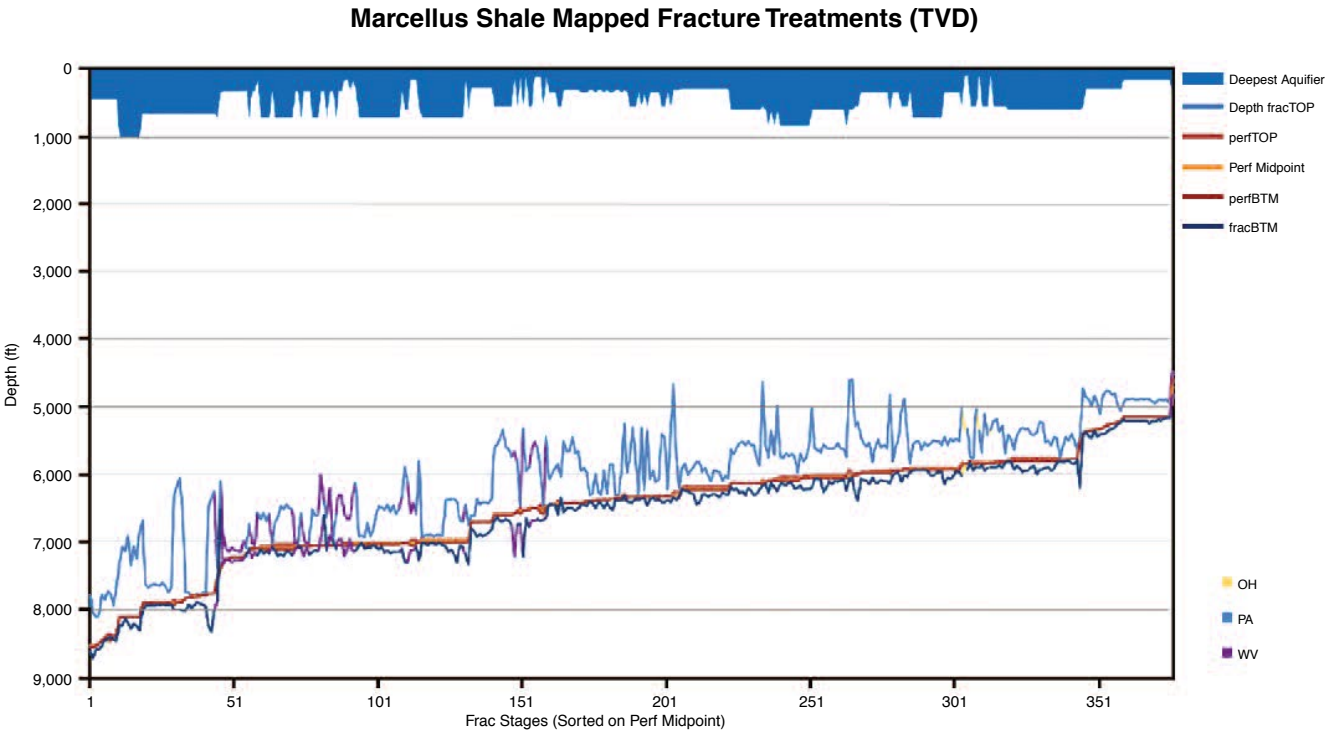

Figure 6. Estimated fracture propagation determined by micro-seismic monitoring of hydraulic fracturing operations in the wells drilled in the Barnett and Marcellus shale plays.
Surveys show created fracture relative to the position of the lowest known freshwater aquifers, shown in blue at the top of each panel (Fisher, 2010).

Box 2: Induced seismicity

The energy associated with the injection (or withdrawal) of fluids from the subsurface can cause the brittle failure or fracturing of rocks, resulting in seismic events. This can happen in three ways in association with UGD: 1) during the process of stimulating reservoirs with hydraulic fracturing procedures; 2) during the withdrawal of gas and water during production; and 3) during the reinjection of flowback fluid and/or water that is produced in association with the production of gas. In the first two cases, the seismicity that results occurs within the producing reservoir and is of a very low magnitude. It is termed "micro-seismicity" and includes events with moment magnitudes of -1 to -4 Mw. Generally seismic events need to exceed a moment magnitude of 2 to be felt.

The process of hydraulically stimulating a productive interval in a reservoir by definition exceeds the elastic strength of the rock and causes localized brittle failure that creates fractures to connect the wellbore with the matrix of the reservoir. The process results in many micro-seismic events that can be recorded, but these cannot be felt at the surface, and the risks to people and property are minimal. The distribution and geometry of these micro-seismic events are used by the industry to refine its understanding of the effectiveness of hydraulic stimulations. Similarly, as water and gas are removed from a producing formation, there exists the possibility that the decrease in volume of the pore system will be associated with micro-fractures that form within the reservoir and result in micro-seismicity. These events are analogous to those induced in a hydraulic fracture stimulation procedure, but are generally of a smaller moment magnitude. Also in a similar manner, gas-producing companies may use the distribution and geometry of these micro-seismic events to enhance their understanding of the drainage distribution of gas from the reservoir.

The third way in which seismicity can be induced is by the reinjection of fluids into a saline water-filled aquifer in the deep subsurface (Johnson, 2013b). The aquifer is often a deep and hydraulically isolated formation with a high storage capacity. The production of large volumes of fluids from the subsurface in association with produced gases and liquid hydrocarbons from unconventional reservoirs is an operational challenge. The injectant is either flowback fluids from hydraulic stimulation procedures during the completion of wells and/or formation water that is produced along with the gas during the production period. A significant difference of this source of seismicity from the previous two is that the volume, duration and rate of fluid injection can be much higher (tens of millions of gallons). If the volume or rate of injection is high enough, and if a critically stressed fault lies within the elevated pressure window, the stress caused by the pressure of the injected fluids will exceed the elasticity of the rock in either the storage reservoir or in the overlying/underlying seals. Thus the injection may cause brittle failure of the rock and result in a seismic event. The geometry of the faulting limits the scope of the risk.

Risks of damaging seismicity or other negative consequences resulting from the aforementioned processes are twofold. First, if the storage horizon in a wastewater disposal well is deep enough and lies adjoining a brittle formation that is critically stressed and contains large pre-existing fractures (often the crystalline basement complexes that underlie the sedimentary column in a basin) and the injection rates and volumes are high enough to cause brittle failure, the initiation of a seismic event is possible. If a critically stressed fault is perturbed by the pressure field, a seismic event could be triggered that would be proportional to the displacement or movement on the fault. Depending upon the type of bedrock and unconsolidated materials in the region that are shaken, varying amounts of damage are possible at the surface.

Appropriate adherence to existing rules and subsurface policies that restrict the volumes and injection rates to pressures below the threshold of brittle failure are the most common means of managing this risk. Zoback (2012) has recommended a set of **five basic practices that could be used by operators and regulators** to safeguard an injection operation from inducing seismicity when pumping fluid into the subsurface: 1) avoid injection into active faults and faults in brittle rock; 2) formations should be selected for injection (and injection rates should be limited) to minimize pore pressure changes; 3) local seismic monitoring arrays should be installed when there is a potential for injection to trigger seismicity; 4) protocols should be established in advance to define how operations will be modified if seismicity is triggered; and 5) operators need to be prepared to reduce injection rates or abandon wells if triggered seismicity poses any hazard.

Compared with other risks from UGD, induced seismicity is considered relatively low in both probability and severity of damages and thus is not a major focus of routine oil and gas operations. A recent report by the US National Academy of Sciences (National Research Council, 2013) on induced seismicity states "The process of hydraulic fracturing a well as presently implemented for shale gas recovery does not pose a high risk for inducing felt seismic events and injection of disposal of waste water derived from energy technologies into the subsurface does pose some risk for induced seismicity, but very few events have been documented over the past several decades relative to the large number of disposal wells in operation."

Pollution from surface leaks and spills

At various points in the UGD process, the storage, handling and transportation of potentially hazardous, toxic, radioactive and carcinogenic fluids are required (NYSDEC, 2011; URS, 2011; King, G., 2012). There are inherent risks of human exposure from mishandling these fluids. Holding tanks, tanker trucks, pits and other containers may leak, and chemicals could be spilled, potentially reaching ground and surface waters (King, G., 2012) The risks to human health and the environment (e.g. wildlife) from exposure to uncontrolled releases of chemicals and wastes vary in frequency and magnitude. Even under pessimistic assumptions, the extent of human exposure has been shown to be less than the safety thresholds adopted for regulatory risk management (Gradient, 2013).

To evaluate the frequency of these events, necessary considerations include the rate of development, modes of transportation (pipeline, truck, etc.) and storage mechanisms (pits, tanks, etc.). Frequency may be further delineated by the failure rate associated with each technology (e.g. single- versus double-walled tanks). The volume of a release is inversely proportional to the likelihood it will occur (Rozell & Reaven, 2012). Lower-probability (high-volume) releases are associated with catastrophic failures of containment mechanisms and accidents during transportation.

The magnitudes of the potential impacts from contamination depend on the concentration and chemical composition of the solutes in the water. Thus, where and when unintentional releases may occur will also be a factor in determining the level of risk. Best practices for fluid and waste handling on and off the well pad are complemented by backup containment systems, such as placing synthetic liners below the gravel layer on the well pad (King, H., 2012b). Effective emergency preparedness and response capacities also help to reduce the risks from unintended releases or accidents.

Improper disposal of solid and liquid wastes

Drilling and hydraulic fracturing generate considerable solid and liquid wastes requiring appropriate disposal. Solid material removed from the subsurface to create the wellbore is collected on the well pad and is known to contain elevated levels of heavy metals and other hazardous materials, including naturally occurring radioactive material (NORM) (NYSECD, 2011; King, H., 2012b). After hydraulic fracturing, the flowback water is typically stored on the well pad in lined pits or vented tanks. The quantity and constituents of the fluid waste streams vary within and across formations, and may be concentrated by treatment processes, but they are expected to contain the chemicals from the fracturing fluid and salts, hydrocarbons, dissolved metals and NORM from the reservoir (Rowan *et al.*, 2011; Hammer & VanBriesen, 2012.)

Disposal options for produced wastes should be limited by their potential adverse effects to health and human welfare, as well as to the environment. Disposal of solid or partially de-watered wastes in landfills, on the ground or by entombment (burial) are current practices. Leachate is the primary risk to surface and groundwater quality. Numerous methods for disposal of waste fluids exist, though not all may be appropriate or viable for a particular project. An arid climate is necessary for evaporating waste fluids, and suitable geologic conditions must be present for deep-well injection of wastes. Properly implemented deep well injection of various types of waste (EPA Classes I–V) has been documented to be effective in protecting groundwater (GWPC, 2011).

Constituent concentrations and volumes determine both the effectiveness and cost of treatment processes for waste fluid disposal. For example, conventional sewage treatment plants designed for organic and biological constituents are not effective at removing metals and other dissolved solids common in gas industry wastewater (Wilson & VanBriesen, 2012) and should not be used for disposal (See “Pennsylvania ‘scrambles’ to address wastewater disposal issues” in Box 6, Section 4). Illicit dumping of wastes on the ground and into rivers by waste haulers has been observed (Silver, 2012), but is not known to be widespread.

Precautions must be taken to ensure wastes are disposed safely and permanently. With proper planning and oversight, low-level hazardous wastes may be disposed in a manner that poses negligible risks to surface and groundwater resources (Gray, 1990). Depending on the amount of waste generated and its constituents, specialized facilities may be required to lower the risks to acceptable levels. Opportunities for the beneficial reuse of drilling wastes may also decrease waste disposal requirements (ANL, 2013). Waste manifests, or other systems to track the collection and disposal of wastes generated from UGD, enhance transparency and are viable deterrents to illicit practices.

Failure to properly plug a well

The process for decommissioning an unconventional well is known as plugging and abandonment. It may include the removal of the production casing, which extends from the surface to the producing reservoir. The wellbore is then filled with cement, or more commonly, a series of cement plugs above fluid-bearing formations is used to block fluid flow in the wellbore. The purpose is to permanently isolate the brine and hydrocarbon formations from each other and shallow groundwater horizons that could be connected by flow through the wellbore.

Failure to permanently plug a well may allow brine and other hydrocarbons, particularly methane, to reach the surface and/or contaminate groundwater. The uncontrolled movement of methane in the subsurface, known as stray gas, poses an explosion risk if it accumulates in buildings and also contributes to atmospheric concentrations of methane (NETL, 2007).

Preventing the flow of fluids in the wellbore decreases the potential for deterioration of the mechanical isolation by chemical exposure (Muehlenbachs, 2009; Nichol & Kariyawasam, 2000). However, there is the potential that the plugging process is unsuccessful or is incompletely executed. Long-term monitoring of abandoned wells may be necessary to identify and repair potential issues with mechanical seal integrity beyond well-plugging operations. Well owners may also be neglectful of responsibilities when costs are high and perceived benefits are low (Mitchell & Casman, 2011).

Recommendations

1. Perform baseline measurements of water quantity, characterizing seasonal and inter-annual variability of surface water flows and groundwater levels. Examine water demands for UGD at local and regional scales and assess the potential effects on water resources and the environment in the context of existing uses.

2. Perform baseline measurements of surface and groundwater quality in close proximity to development and where the potential impacts from source degradation are highest (e.g. at a public water supply intake). Monitor water quality and respond to changes that can lead to the discovery of operational or compliance problems.

3. Minimize human exposure to materials and fluids that are hazardous and/or carcinogenic and prevent environmentally damaging releases through proper handling and disposal, and if necessary, remediation. Select the disposal and reuse methods that can adequately contain the types and volumes of fluids used, and monitor containment effectiveness.

4. Characterize both the geological (e.g. frac barriers) and hydrological (e.g. groundwater) systems, and understand how they interact before, during and after UGD. Employ hydraulic fracturing monitoring (e.g. micro-seismic mapping) to assess fracture propagation in new or geologically unique areas. The distance and composition of the strata between the surface and the target gas reservoirs should be deep and impermeable enough that effects in the reservoir do not affect the surface or groundwater systems.

5. Verify that groundwater is properly isolated from fluids in the wellbore before and after hydraulic fracturing. Use processes and materials for wellbore casing that are appropriate for the geologic setting and resist degradation from known chemical, thermal and mechanical stresses in the subsurface. Monitor and maintain well casing integrity until it is properly plugged.

6. Develop applicable risk mitigation strategies to govern development in susceptible areas that contain either known potential technical hazards, such as critically stressed faults and venerable groundwater systems, or activities that may be vulnerable, such as tourism and agriculture.

7. Use appropriate, modern and effective technologies in terms of chemicals, well design, well appurtenances, safety management (i.e. risk identification and assessment, emergency management) and wastewater disposal.

8. Monitor material flow, including: methane emission levels; wastewater composition and volume; chemical and radioactive substance concentrations in deep groundwater; fluid concentrations; and chemical degradation products as appropriate to the risk that these constituents may pose to water resources in an area.

9. Pre-plan well-plugging activities and their costs. Establish clear responsibility for post-abandonment issues. Financial assurance programs have been used to provide an economic incentive to well owners for performing plugging activities.

Air

One of the principal benefits of UGD is the reduction of combustion emissions relative to other fossil fuels though gas is not as clean as nuclear power or renewables. For example, combustion of coal is a major source of particulate pollution, which is one of the most health-damaging forms of air pollution (Muller *et al.*, 2011). Combustion of natural gas produces much less particulate matter pollution than coal (WBG, 1998), However, developing unconventional reservoirs is an energy-consuming process, and uncontrolled emissions in the process could partially undermine these air-quality gains of gas. The emissions' sources may be temporary or continuous, mobile or stationary, and localized or dispersed over a large area. The physical effects may extend to human health, infrastructure, agriculture and ecosystems (Litovitz *et al.*, 2013), but these impacts depend significantly on the context of development, including regional climate conditions and population distribution. In some communities, air pollution associated with UGD has been a greater concern than water pollution (CC, 2013).

Dust

The construction of the well pad and access roads (both grading and laying gravel) and the movement of trucks and heavy machinery on or near the well pad for drilling and hydraulic fracturing generate dust. In addition to potential environmental impacts (EPA, 2012a), breathing this dust can cause or exacerbate respiratory ailments in workers and people living or working downwind (Davidson *et al.*, 2005; Esswein *et al.*, 2013). Silica dust is generated as the proppant is transferred, blended, and injected with the slickwater (hydraulic fracturing fluid). Potential exposure to unsafe levels of respirable crystalline silica (sand <10 μ in diameter) represents an occupational risk associated with several industries. Breathing silica can lead to the incurable lung disease, silicosis, and has also been associated with lung cancer and chronic obstructive pulmonary disease (NIOSH, 2002).

Fugitive dust is managed through the use of well-understood dust control and suppression methods. Dust suppression, usually by application of water and/or other chemicals, may be sufficient to minimize the amount of dust generated from construction and the movement of equipment and trucks on the well pad (EPA, 2012a). The risks to workers from respirable silica dust on the well pad may be reduced, where the sand transfers and blend activities occur, by the use of housed mixing mechanisms and appropriate respirators. Process improvements to limit or capture dust (e.g. employing "dust collectors") during hydraulic fracturing operations are recommended by the US National Institute for Occupational Safety and Health (OSHA, 2013).

Mobile and transient combustion emissions

Mobile internal engine combustion emissions occur during the construction, drilling and hydraulic fracturing stages of UG development. Hundreds to thousands of truck trips may be necessary to bring equipment, supplies and people to and from the well pad (NYSEDC, 2011). Transportable diesel engines provide the power for well drilling and casing operations, as well as for hydraulic fracturing. Diesel fuel consumption ranges from 1,150,000–320,000 liters per well (Clark *et al.*, 2011).

Emissions from internal combustion engines include nitrogen oxides (NO_x), sulfur oxides (SO_x), carbon dioxide (CO_2), volatile organic compounds (VOCs) and particulate matter. The principal risks are to human health from inhalation of particles and ozone, the latter being formed from the photo-oxidation of VOCs and NO_x. Severity of the adverse health impacts range from minor eye and throat irritation to serious or fatal respiratory and cardiopulmonary problems (Litovitz *et al.*, 2013). The CO_2 emitted from these engines is a greenhouse gas, though minor in magnitude compared with other major point sources of CO_2 such coal-fired power plants.

Mobile emissions are transient, with average air concentrations roughly proportional to the drilling activity level in a particular area. Because operating heavy machinery and truck transport represent costs to the operator, there is a financial incentive to minimize fuel use and associated emissions. When water is transported by pipelines truck trips may be shortened or avoided altogether (King, G., 2012). Proper maintenance and use of more efficient equipment can reduce emissions. Diesel fuel is widely used in generators and trucks. Switching fuel from diesel to natural gas reduces some of the combustion-related emissions (King, G., 2012).

Stationary combustion emissions

Produced gas from individual wells is aggregated through a network of gathering pipelines. When the natural pressure of the gas is too low, it is introduced to transmission and distribution pipelines through electric-powered compressors, which may be grid-connected, but are more commonly co-located with natural gas fuelled generators (Burklin & Heaney, 2005; Armendariz, 2009; EIA, 2013a). Heavier hydrocarbons may be transported in pipelines, but are also commonly shipped in transportable tanks (NPC, 2011). Energy consumption for natural gas compression is proportional to throughput and the pressure requirements of the receiving pipeline.

From the associated combustion emissions, there are risks from the formation of ozone and from increasing greenhouse gas emissions. The emissions from natural gas compression are stationary and will occur over the operational life of a facility. Proper maintenance and use of leaner burning compressors can reduce these emissions (Burklin & Heaney, 2005). Emissions can also be reduced by using electric motors to power the compressors (Armendariz, 2009).

Fugitive methane emissions

From the wellhead to burner (and all points in between) there are multiple places from which natural gas may escape to the atmosphere. Potential sources include pumps, flanges, valves, gauges, pipe connectors, compressors and other components (Armendariz, 2009). Natural gas losses in the system are known as fugitive methane emissions, and they may occur as intentional releases or unintentional leaks. A large source for intentionally released methane is the pneumatic valves commonly used by the gas industry as liquid level controllers, pressure regulators and valve controllers (EPA, 2006). Unintentional releases may be the result of poor installation and maintenance, as well as from expected wear of sealed components by rust or corrosion (Armendariz, 2009). Natural gas compressors are another potentially large source of fugitive methane emissions. During normal operation of compressors, natural gas may leak from the packing systems (NYSDEC, 2011) and will be intentionally released when performing maintenance (Gillis *et al.*, 2007).

Fugitive methane emissions increase greenhouse gas concentrations in the atmosphere, and are of special concern because of methane's large greenhouse gas potential. However, quantifying these emissions may be difficult given their dependency on operator practice, and the fact that they are dispersed over a wide area and change with time (e.g. as components wear). Limiting fugitive methane emissions can be economically motivated because the captured gas has commercial value when sold in the marketplace (Gillis *et al.*, 2007). Routine inspection and maintenance of the components from where leaks typically occur can reduce fugitive methane emissions. Minimizing the intentional releases of natural gas is possible by switching from high- to low-bleed pneumatic valves or by controlling these valves with compressed air or electricity (EPA, 2006) and using closed-process design in treating backflow and waste. Although a recent study of methane emissions at 190 on-shore natural gas sites in the United States found an overall smaller rate of methane emissions – during drilling operations – than had been suggested in modeling exercises and similar studies, pneumatic controllers and selected leaks were still significant (Allen *et al.*, 2013; Revkin, 2013).

Box 3: Greenhouse gas emissions

Greenhouse gas emissions from natural gas production, transmission, distribution and use come from fugitive methane emissions and fuel combustion (Jaramillo *et al.*, 2007). A number of GHG life cycle analyses have estimated emissions throughout the natural gas life cycle (Venkatesh *et al.*, 2011; Arteconi *et al.*, 2010; Odeh & Cockerill, 2008; Ally & Pryor, 2007; Okamura *et al.*, 2007; Tamura *et al.*, 2001; Kim & Dale, 2005). However, unconventional gas production utilizes unconventional methods. The concern for increased emissions from horizontal drilling and hydraulic fracturing has stimulated a recent spate of GHG life cycle analyses (Howarth *et al.*, 2011; Jiang *et al.*, 2011; Hultman *et al.*, 2011; NETL, 2011; Burnham *et al.*, 2011; Stephenson *et al.*, 2011). The studies examined generic shale gas plays (Howarth *et al.*, 2011; Hultman *et al.*, 2011; Burnham *et al.*, 2011; Stephenson *et al.*, 2011) or specific plays (e.g. Marcellus or Barnett). Also, these studies looked at a variety of end uses (e.g. electricity generation, transportation). All make a myriad of modeling assumptions that result in some variability in results. The figure below shows the overall GHG emissions from the well to the plant gate (through the transmission system) from each of the studies. For the Howarth *et al.* (2011) study the results using 100-year global warming potential (GWP) values for methane are presented for comparison purposes, though the 20-year GWP values are relevant to shorter term impacts.

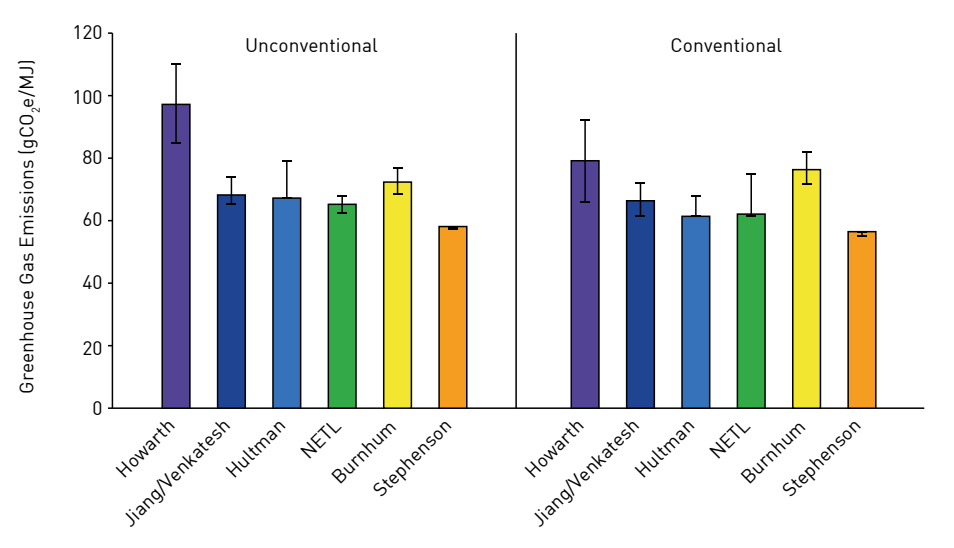

Figure 7. Greenhouse gas emissions: unconventional versus conventional

Weber and Clavin (2012) review the studies shown in the figure above. They reconciled differences in upstream data and assumptions and conducted a Monte Carlo uncertainty analysis of the carbon footprint of both shale and conventional natural gas production. They found the "likely" upstream "carbon footprint" of natural gas production from conventional or unconventional sources to be largely similar, with overlapping 95% uncertainty ranges of 11.0–21.0 gCO_2e/MJ for shale gas and 12.4–19.5 gCO_2e/MJ for conventional gas. The upstream emissions represent less than 25% of the total emissions from heat production, electricity, transportation services or other functions.

Conducting life cycle assessments of UGD

Countries with sufficient UG resources should conduct comprehensive life cycle assessments (LCAs) of current and potential natural gas production chains. Ideally, LCAs should include a sensitivity analysis (a systematic procedure for estimating the relative impacts that various factors in the chains may contribute), and a probabilistic analysis, as a way to incorporate uncertainty into the analysis. Assessments should initially be completed using a generic scenario to account for the many potential factors associated with UGD, in contrast to the various other potential sources of energy (electricity, heat and transport fuel). Region-specific scenarios should then be created to incorporate specific geological and hydrological conditions.

Air pollution from liquids separation processes

After hydraulic fracturing, the pressure on the formation is reduced, allowing fluids to flow from the formation into the wellbore. Over a period of several hours to a few days, water volumes reaching the surface are large and will dominate the flow that includes some gas and associated heavier hydrocarbons (known as condensate). During this time, the co-produced gas may be vented or flared (burned) at the same time that the upward flowing fluids are directed into open pits or holding tanks on the well pad. In wet gas production, hydrocarbons will also be present in the wastewater. The ratio of gas to liquid flow in the wellbore increases quickly, and eventually the produced gases, primarily methane, can be recovered through the use of separation technologies, though continued flaring is common if there is no outlet (market) for the produced gas (NYSDEC, 2011). The process of well completion is finished when the wellhead or "Christmas tree," a structure of valves and pipes to control the flow of gas, is bolted to the top of the casing that extends to the surface.

The production stream experiences a series of pressure drops where water and condensate may drop out and damage the pipelines. On-site separation (e.g. glycol dehydration) to remove these fluids or heating processes are commonly employed to prevent the inclusion of water and condensate en route to gas processing facilities and/or compression stations. The water and condensate separated from the gas are stored in vented tanks and collected periodically from the well pad in tanker trucks for use or sent to processing for disposal (NYSDEC, 2011; Armendariz, 2009). In areas where the fraction of condensate in the production stream is high, gas-processing facilities are used to create two hydrocarbon streams – one composed of mostly heavier hydrocarbons and the other primarily methane. Fractionation facilities are used to separate the heavier hydrocarbon stream into its separate components, namely propane, ethane and butane, each with distinct commercial value (NPC, 2011).

When the water and liquid hydrocarbons are removed from the gas stream, hazardous air pollutants (HAPs) such as benzene and other VOCs, including hydrocarbon vapors, may be released to the atmosphere. Such VOC emissions will occur throughout the life cycle of a well (Litovitz *et al.*, 2013; Armendariz, 2009). Some of the emissions will be released during the separation processes and others may be released as off-gas from stored flowback and/or produced water that is kept in open pits or in large, vented tanks.

To minimize GHG emissions from venting and flaring during the initial "flowback" phase of production, portable separation technologies capable of handling high-volume flows of liquids are increasingly used (Litovitz *et al.*, 2013). Use of these low-emissions or "green" completion technologies is limited by the availability of gathering pipelines to transport the recovered hydrocarbons. Water and liquid hydrocarbons produced at low rates over the life of an unconventional gas well may also be separated from the produced gas stream and recovered at the well pad for disposal or sale. Efficient capturing of the produced hydrocarbon fluids is possible through the use of widely available vapor recovery units (Gillis *et al.*, 2007). The alternative is to vent or flare liquids produced with the gas, though flaring has the advantage of reducing HAP, VOC and methane emissions into the atmosphere (Armendariz, 2009). The concentrations of volatile elements and other toxics in the produced water, the type of storage, and the amount of time the waste fluids spend on the well pad are key factors in determining the magnitude of local and regional risks to air quality and human health.

Recommendations

1. Select dust management practices that are compatible with local conditions, minimize environmental impacts and limit human exposure. Consider operational changes and remedies to limit fugitive silica dust emissions.

2. Perform baseline measurements of local and regional air quality. These may include (at a minimum) NO_x, SO_x, methane and VOCs. Monitor air quality and respond to changes appropriately.

3. Minimize methane emissions through all phases of unconventional gas development and across the infrastructure used to produce and deliver natural gas to consumers. Limit venting and flaring and perform regular maintenance to prevent leaks.

4. Measure and monitor human exposure to air pollutants. Consider the potential effects on community health in siting decisions for well pads and related infrastructure (e.g. compressors).

5. Incorporate potential air emissions in regional land use planning efforts

Section 3:

The need for political legitimacy

Political legitimacy implies that the national, regional and/or local legal systems permit (or even encourage) exploration, production and transport of unconventional gas resources. Moreover, in specific communities where UGD occurs, legitimacy means that local citizens and their leaders are prepared to accept some risks and disturbances in daily life in exchange for perceived benefits.

If a nation, region or locality appears to be unreceptive to UGD, developers and their investors are likely to shift resources to other jurisdictions where the political environment is encouraging. In this respect, the sites for UGD around the world will be influenced by political considerations as well as by geological conditions and economic promise.

In this section, we examine the recent political history of UGD regulation in several areas. By presenting short case studies from jurisdictions in North America, Europe and Asia, we seek to identify factors that may help explain why UGD is politically more legitimate in some jurisdictions than others. The case studies presented are not comprehensive, but serve as examples of types of political activities around the world. Not all areas are covered. There is, for example, recent policy activity in Australia on this topic (SCER, 2013; ACOLA, 2013) but it is not included in the list of case studies. The case studies also provide an empirical foundation for IRGC's recommendations related to the political legitimacy of UGD. The recommendations are timely, since some jurisdictions have not yet established regulatory policies toward UGD or are refining the policies they have.

North America

Canada and the United States are similar in two respects – both countries have long histories in oil and gas production, and both countries have been led by political leaders who favor development of an UG industry. In Canada, prime ministers Jean Chretien (Liberal, 1993–2003) and Steven Harper (Conservative, 2006–present) have supported expanded gas development, as have presidents George W. Bush (Republican, 2001–2008) and Barack Obama (Democrat, 2009–present).

Canada

The Canadian natural gas industry, which has operated since the 19th century, is seen as an export-oriented industry and thus a source of jobs and prosperity. The rate of gas production in Canada is steadily rising, despite the declining yields from conventional plays, because of the growth in unconventional production (Kohl, 2012). Canada also is attracting foreign capital (including Chinese investors) to help build its shale gas industry (Penty & van Loon, 2012; Krugel, 2012).

The timing of Canada's growth in shale gas production could not be better: the market for Canadian gas in the US is declining (as US gas production rises) (Persily, 2012) but buyers throughout Asia (especially Japan, China and India) are offering hefty premiums for Canadian gas, well above current market prices in the US.

As Canada develops its UG resources, it is a mistake to think that it will occur only in one or two provinces. Regions with particular geological promise include the Horn River Basin and Montney Shales in northeastern British Columbia; the Colorado Group in Alberta and Saskatchewan; the Utica and Lorraine Shale regions in Quebec; and the Horton Bluff Shale in New Brunswick and Nova Scotia.

The politics of shale gas production in eastern Canada are far more contentious than in western Canada, where energy extraction has been a way of life for decades and shale gas plays can be taken without having a noticeable impact on large population centers. Sensitivity about shale gas production in Quebec is accentuated because some of the plays are located near the St Lawrence River, where there are densely populated communities and valuable agricultural fields (Blatchford, 2012).

UGD in Canada has not occurred without some adverse incidents. In September 2012 a company was performing a hydraulic fracturing operation in Alberta when drillers inadvertently perforated above the target reservoir at a depth of 136 meters. The government investigated and determined that the incident posed an insignificant risk to drinking water resources, but the company was required to implement a groundwater monitoring program. Enforcement action against the company was also taken, as it was determined that a variety of industry best practices were not followed (ERCB, 2012).

Organized opposition to UGD has already been passionate in the province of Quebec, as indicated by emotionally charged public hearings and community demonstrations. A large-scale, grassroots citizens' march through Montréal in 2011 was accompanied by a call for a 20-year moratorium (Blatchford, 2012).

The controlling Liberal Government in Quebec responded in 2011 with a temporary moratorium in order to allow more time for studies of potential ecological risks (Dougherty, 2011). When the 2012 elections brought into power a new government with strong links to the environmental movement in Quebec, the new environment minister expressed the public view that "I don't foresee a day when there will be a technology that will allow safe exploitation (of shale gas)" (Reuters, 2012b).

For the Canadian industry to thrive, the government must also foster pipeline development and liquefied natural gas export terminals. Both are significant infrastructure investments with challenging regulatory and public-acceptance issues (Eaton, 2012).

Canada already has an extensive array of pipelines for moving natural gas (NRC, 2013). Networks of gathering pipelines move gas from wells in productive fields to processing facilities, while feeder lines move hydrocarbon products to the long-distance transmission lines. Several large-volume transmission lines deliver product to industrial users, refineries, local distributors and, importantly, to the United States.

The challenges of pipeline development are exemplified by the troubles facing the "Mackenzie Gas Project" in Canada. In 2004, a consortium of large companies proposed a new 750-mile, C$15.4 billion pipeline that would connect Arctic gas fields with the rest of Canada and the United States. Operations were to begin in 2009.

A review by a Canadian Government expert panel took much longer than expected, as some First Nation communities and environmental groups raised concerns about threats to local species and native cultures. There were also concerns that greenhouse gas emissions could rise if the gas is used to heat and upgrade oil sands.

After five years of study, the panel concluded that fish in the Mackenzie River would not be harmed, that regional planning could protect polar bears, caribou and beluga whales and that greenhouse gas emissions might be curtailed due to diminished use of coal (Krauss, 2009). Canada's National Energy Board took another year to issue a formal approval (Dvorak & Welsch, 2010) but the project experienced additional delays due to a lack of agreement over taxes, royalties and financing arrangements. Most recently, the corporate sponsors have curtailed spending on the project and delayed the start date to 2018, in part due to the unexpected growth of UGD in the United States (CBJ, 2012).

Priorities in Canada are shifting somewhat from serving US customers to serving Asian and European customers. To reach those profitable markets, the gas must be liquefied and shipped across the ocean to terminals at Asian and European ports. Canada does not have adequate LNG export terminal capacity to meet the growing demands for gas in Asia and Europe. Like pipelines, export terminals require large capital investments, regulatory approvals and local public cooperation.

The US Department of Energy reports that 10 new LNG export terminals have been proposed (two in Canada and eight in the United States). The multi-year approval processes for LNG export facilities can be quite complex in both countries, and the US Government has not yet made a decision about the extent of LNG exports that are in the best interests of the United States (DOE, 2012).

LNG export terminals are not simple to arrange. Consider the new plan by a Canadian energy company (Pieridae Energy Canada) to build a large LNG facility in the small port town of Goldboro, Nova Scotia (LNGWN, 2012). The facility would be located near a 1,400-kilometer transmission pipeline system and would be equipped to store, liquefy, load and export gas. Much of the gas would be supplied by unconventional plays in eastern Canada. Project endorsers include the Premier of Nova Scotia and local political leaders in Goldboro and the Municipality of the District of Guysborough, Nova Scotia. The Goldboro facility is many years away from operation, but the roll out of this ambitious plan illustrates the extent of local and provincial cooperation necessary for a credible launch of such a large infrastructure project.

In summary, with the notable exception of Quebec, the political environment for UGD is quite favorable in Canada. There are discussions within the federal government considering subsidies for the construction and operation of LNG terminals. In western Canada particularly, the permitting process for UGD is already operational. Decisions are in the hands of professional civil servants because the legitimacy of UGD is not a major political issue. While Canada's biggest customer for gas exports has historically been the United States, the Canadian industry, in collaboration with local, provincial and national officials, is gearing up to export large volumes of gas to Asia and Europe.

United States of America

The system of property rights in the United States varies from state to state. In some, many of the surface landowners have retained their subsurface mineral rights; in other states they have not. State laws also differ on rules for the management of gas production and on whether neighboring owners are obligated to allow sales of gas from a shared reservoir (forced pooling). Even within a single state

(e.g. Texas), subsurface mineral rights may be handled differently in different parts of the state (Olson, 2013).

Despite the complexity of American property rights, state laws often provide incentives for gas development. Landowners often receive financial royalty payments from natural gas production that operates on their property. Property owners may also receive a "bonus payment" at the point of sign up for gas development, in addition to royalty payments. For some individual landowners, the financial benefit can run into the tens of thousands of dollars or more, depending on the volume and price of the gas that is sold (Plumer, 2012). This system of royalty payments is not unique to UGD, as it also fostered the development of conventional oil and gas resources as well as minerals in the US.

Three states (Arkansas, Pennsylvania and Texas) currently account for much of the UGD in the US, but other states (Colorado, Michigan, Ohio and West Virginia) are rapidly expanding their contributions or are planning UGD (e.g. Bell, 2013a; DN, 2013). The states of California and Illinois have decided against a prohibition of UGD and instead have enacted new regulatory systems that permit UGD under stringent and relatively burdensome constraints (Wernau, 2013). It is too early to assess whether California or Illinois will see significant UGD (Conrad, 2013; Dean, 2013). New York State, which we discuss below, has enacted a legislative moratorium until 2015.

Unconventional gas wells in the United States are not restricted to remote, unpopulated areas. A recent analysis of population data from 11 energy-producing states found that 23 US counties, with more than four million residents, each had more than three new wells (since 2000) per square mile. At least 15.3 million Americans live within a mile of a well that has been drilled since the year 2000 (Gold & McGinty, 2013).

Public opinion in the United States varies from state to state but is largely receptive to UGD. In November 2011 Deloitte administered an online survey to a representative sample of 1,694 adults living in the United States (Deloitte, 2012). The vast majority of respondents see natural gas as a clean energy resource whose production and use is closely linked to job creation. Only about 20% of respondents felt that the risks of shale gas development outweigh the benefits. Although citizens living near active fields are likely to have higher levels of awareness, about 40% of US respondents were unfamiliar with hydraulic fracturing (i.e. had never heard of it or were not at all familiar with it). The most frequently cited concerns about shale gas development were water contamination (58%), impact on surface land (49%), amount of water used (34%) and air emissions and earthquakes (both 29%). In a separate study, residents of both Michigan and Pennsylvania were found to be supportive of UGD (Brown *et al.*, 2013; AP, 2012b).

Oil and gas operations in the US are subject to some federal regulations that set minimum performance standards and goals, but the bulk of regulatory oversight is governed by the laws of the individual states. In 2005 the US Congress exempted hydraulic fracturing from national drinking water regulations that apply to underground injection of fluids. This exemption gives states flexibility to choose how to regulate hydraulic fracturing, and there is some variance in how different states exercise their discretion.

More generally, the political demand for regulation of UGD varies considerably across the United States (i.e. from a fairly pro-development permitting system in the state of North Dakota to a prohibition of UGD in New York). To illustrate this variability, we consider the regulatory and political environments in three states that are important to the United States' future as a gas producer: Texas, Pennsylvania and New York.

Texas

The Barnett Shale is a formation that extends from the region of Dallas-Fort Worth, Texas, south and west, covering 5,000 square miles. Hydraulic fracturing and directional drilling have enabled the Barnett Shale to become the largest source of UGD in the US (TRC, 2012).

Permit applications are evaluated by the Texas Railroad Commission, a regulatory agency once responsible for railroads and now principally responsible for oil and gas regulation (Ryan, 2012). Each UGD proposal in Texas is evaluated through the same permitting process that covers conventional gas projects – a review process that entails detailed geological and engineering assessments.

The commission has an unusual structure: the three politicians who lead the agency are elected in periodic statewide contests (Ward, 2011; Magelssen, 2012). They make policy decisions and oversee the work of a professional staff that includes engineers, scientists, lawyers and other professionals. Since the commissioners serve fixed terms of office and are not removable at the will of the Governor of Texas, the commission has a measure of independence that is somewhat uncommon among US regulatory agencies.

The commission is an active regulatory body. New regulations were adopted recently to reduce flaring and venting at oil and gas wells and to disclose the chemicals used in the drilling fluids during hydraulic fracturing (UGCenter, 2011; WONC, 2012b).

The rapid growth of UGD in Texas has precipitated some controversy. Since the UGD projects are situated in the midst of one of the nation's largest metropolitan areas (Dallas-Fort Worth), they can be a source of community irritation due to noise, traffic accidents and congestion, and odors and air contaminants. Another concern is that freshwater resources are scarce in parts of Texas, yet hydraulic fracturing consumes large amounts of water.

One of the most hotly contested issues was the US Environmental Protection insertion into the Parker County drinking water contamination case. EPA has broad authority to intervene when drinking water is contaminated, and gave credence to complaints from two Texas residents, despite the technical objections of the Texas Railroad Commission (Earthworks, 2011). At issue is not whether contamination occurred, but whether the contamination was due to UGD.

The EPA ultimately dropped its claim against the drilling company after geochemical fingerprinting analysis of contaminated well water indicated that methane likely came not from the deeper Barnett shale but from a shallower formation called the Strawn (Everley, 2013; Gilbert & Gold, 2012; Armendariz, 2013). Residents continue to pursue their complaints (Soraghan, 2013). The EPA has also dropped investigations of methane contamination in Pavillion, Wyoming and Dimrock, Pennsylvania.

The key contaminant at issue, methane, is naturally occurring and can migrate, so its mere presence in drinking water does not necessarily indicate that gas exploration or production caused the contamination. In Texas the issue is further complicated by the presence of many abandoned conventional wells, which also can be a source of residual contamination.

The Texas Railroad Commission contends there are no documented cases of hydraulic fracturing leading to groundwater contamination in the state of Texas, despite more than six decades of reservoir stimulation through hydraulic fracturing (IOGCC, 2013). The EPA now has a large-scale national investigation of the water quality issue as it relates to UGD under way (EPA, 2013).

Pennsylvania

The Marcellus Shale is up to 9,000 feet beneath southern New York, northern and western Pennsylvania, the eastern half of Ohio and most of West Virginia (Abdalla, 2012). UGD began in Pennsylvania in 2007 and has proliferated rapidly. By December 2012, 5,700 wells had been drilled and 3,600 wells in Pennsylvania were producing gas from the Marcellus Shale.

Over 85% of the Pennsylvania UG production comes from just six of the state's 67 counties, half of it coming from two counties on the border of the State of New York. The second largest area of production is in the southwest region of the state near Pittsburgh and the Ohio border (Magyar, 2012b).

Pennsylvania is not known like Texas to be a long-term player in energy production but the history books reveal otherwise. More than 350,000 oil and gas wells have been drilled in Pennsylvania since the first commercial oil well was established in Titusville, Pennsylvania in 1859 (Pahouse, 2013). The state is known for its industrial strength, and the declining prices of natural gas have helped Pennsylvania attract new manufacturing plants that use gas as a feedstock (Casselman & Gold, 2012).

Due to decades of experience with severe air and water pollution from coal use and steel production, Pennsylvania also has a vigorous environmental movement and a strong regulatory tradition (Kury, 2013; Tarr, 2005). Citizens for Pennsylvania's Future (PennFuture) is a statewide public interest organization that has played a leadership role in highlighting the environmental risks of UGD and advocating for stringent regulation of the industry (PennFuture, 2012). Environmental advocates have been pitted against a strong advocacy effort from industry that includes everything from industrial donations to local elected officials to television commercials in western Pennsylvania touting the virtues of UGD (Schwartzel, 2012).

Permits for UGD are submitted to Pennsylvania's Department of Environmental Protection (Bureau of Oil and Gas Management). The bureau has regional offices around the state that review and process permit applications. Concerns have been raised that the regional offices were not staffed adequately to respond to the surge of drilling proposals (Abdalla, 2011).

Unlike Texas, where the top regulators are elected commissioners, leading Pennsylvania regulators serve at the pleasure of the Governor of Pennsylvania – a more common arrangement under US state laws. Thus, the civil servants who regulate shale gas are ultimately subordinate to the Governor of Pennsylvania, and thus the opposing interest groups seek to persuade the governor to favor their position on key issues.

Pennsylvania's UG industry grew enormously before the state could muster the consensus to modernize its regulatory system. In early 2012 Pennsylvania's Governor finally signed a 174-page law that refines the way UGD is regulated (Kasey, 2012).

Each county was authorized to levy an "impact fee" on UGD that is indexed to the prevailing price of gas. The state is to collect the

fees and distribute them to state agencies (40%), municipalities (40%) and counties (20%). About US$200 million in fees were collected in 2012.

As part of a legislative compromise that ensured enactment of the impact fee, counties and municipalities are prohibited from using their planning/zoning authority to impose non-regulatory restrictions on oil and gas operations. This provision, which was challenged successfully in constitutional litigation, was aimed at providing uniformity for UG producers and service companies that operate in multiple jurisdictions simultaneously.

The state's Oil and Gas Act was also amended to increase the bonding amounts required of UG firms while the setback requirements were widened to protect homes and waterways. Stronger notification requirements are provided for landowners, stricter measures are applied against spills and some new disclosures about use of drilling fluids are required.

Public opinion in Pennsylvania, where there are growing concerns about the risks of UGD, is nonetheless favorable toward UGD, especially in communities where drilling occurs. The Center for Social and Urban Research at the University of Pittsburgh surveyed 403 residents of Washington County (near Pittsburgh), where about 600 gas wells are operating. Forty-nine percent of respondents supported UGD, 29 percent opposed UGD, and 22 percent did not have an opinion. More than three quarters of respondents perceived economic opportunities from UGD and about one third of respondents had a family member who had signed a lease with a gas drilling company. A majority of respondents (58%) perceived at least a moderate threat to the environment from UGD but those concerns were not strong enough to favor the kind of prohibition on UGD that was enacted in Quebec (Heuck & Schulz, 2012).

For the foreseeable future, it appears that UGD will flourish in the State of Pennsylvania, as leaders of both political parties in the state have endorsed the practice, assuming proper regulations are followed (AP, 2012a). Recent state regulations and the new Pennsylvania legislation are likely to reinforce the legitimacy of UGD throughout the state (Abdalla, 2011), though it is not clear whether the Pennsylvania legislation will serve as a model for other states (Rabe & Borick, 2013).

New York

The State of New York was the United States' first producer of oil and gas. Early in its deliberations on UGD, in 2008, the governor made a determination that departed from the regulatory treatment in Pennsylvania and Texas by designating that UGD is to be treated as a distinct operation, different from conventional oil and gas development. This unique determination, prompted by pressure from environmental groups within the state, triggered a requirement for a supplementary environmental impact assessment, which in turn led to a de facto moratorium on UGD until the environmental issues were resolved (CNN, 2011).

The moratorium gave proponents and opponents valuable time to raise money, develop strategy and mobilize opinion for or against UGD. It also strengthened the hands of those landowners in New York who were seeking better terms on the leases they signed with energy companies (Magyar, 2012a). Both developments have reduced the attractiveness of New York to energy companies.

In 2011, after completion of the environmental study, the governor proposed for public comment a compromise policy where UGD would be banned permanently in state parks and other public lands, in the New York City watershed, in the Syracuse watershed and near some other state aquifers. However, the proposal leaves 85% of New York's Marcellus Shale open for drilling, since five counties near the Pennsylvania border would be allowed to pursue UGD.

Under the governor's proposal, each town or community in those counties would have the power to decide whether to permit or prohibit UGD (Hakim, 2012). The governor appears to be sensitive to the preferences of some towns in upstate New York that support UGD, in part because of the economic boost it has provided to nearby counties in Pennsylvania. In his 2013 State of the State speech, the governor highlighted the need for more economic development in the depressed upper state counties near Pennsylvania. Meanwhile, as his speech was delivered, about 1,000 people gathered in Albany (the state's capital) in protest, urging the governor to enact a complete ban of UGD (Wolfgang, 2013).

After more than four years of organized advocacy by groups on both sides of the issue, public opinion in the state is about equally divided, with slightly more voters trusting opponents of UGD than supporters of UGD (SRI, 2011). About 40 upstate communities in New York have banned UGD, and similar bans are under consideration in 90 communities. Sixty communities, most of them in the five-county region that might be free to drill under the governor's plan, have passed resolutions indicating that they will permit UGD in accordance with state regulations. The political battle in south-central New York's Otsego County has been quite pitched, with opponents appearing to have gained the upper hand. The number of Otsego towns with bans or moratoriums on UGD has increased from five to nine from mid-2011 to early 2013 (Wines, 2013).

In summary, the State of New York has yet to find a sustainable policy on UGD and, in the interim, no permits for UGD are being issued. The governor has delayed a final decision on UGD several times, primarily so that various studies could be undertaken, including a new human health impact study. Most recently, the New York General Assembly in Albany enacted a temporary statewide moratorium on shale gas development. Thus, the future for UGD in the State of New York remains quite cloudy.

Overall, the political and legal environment for UGD in North America is not monolithic. For example, within Canada the situation in Quebec is quite different from that in Alberta. And even two political jurisdictions that border each other (e.g. New York and Pennsylvania) can have sharply different regulatory policies toward UGD. From a standpoint of a national policy, however, both the United States and Canada are aggressive about building an UG industry and, as we shall see, they are open to collaboration with other countries around the world that are considering UGD (State, 2013).

Europe

The European Commission in Brussels has not taken a firm policy position on UGD. In 2011, the European Council called for an assessment of Europe's potential for sustainable extraction and use of conventional and unconventional (shale gas and oil shale) fossil fuel resources, in order to further enhance Europe's security of supply. In 2012 the European Parliament approved (by a vote of 492 to 129) two non-binding resolutions related to UGD: one calls for each member state to make its own policy on UGD and the other calls for each member state to exercise caution if UGD is pursued. A proposed ban on UGD was rejected by a vote of 391 to 264 (Fulbright, 2012).

In January 2012 a study of four member states (France, Germany, Poland and Sweden) concluded that there are no significant gaps in coverage in the current EU legislative framework, at least for regulating the current level of shale gas activities (Philippe & Partners, 2011). Regarding possible areas for improvement of national regulatory frameworks, the study considered it problematic that current public participation in the authorization process for exploration projects is often rather limited. It also stressed that the application of the Environmental Impact Assessment Directive should not be linked to gas production thresholds alone, and it emphasized that regulations should provide legal certainty for investors.

In September 2012 the European Commission published three studies on unconventional fossil fuels, in particular shale gas:

- The first study considers potential effects on the energy market. It reports that unconventional gas developments in the US and global availability of UG may indirectly influence EU gas prices (JRC, 2012).

- The second study on climate impacts indicates that shale gas produced in the EU causes more GHG emissions than conventional natural gas produced in the EU, but – if well managed – less than imported gas from outside the EU, be it via pipeline or by LNG (AEA, 2012a).

- A third study on environmental impacts looks at the potential risks that shale gas development and the associated hydraulic fracturing may present to human health and the environment. It concludes that extracting shale gas generally imposes a larger environmental footprint than conventional gas development due to risks of surface and ground water contamination, water resource depletion, air and noise emissions, land take, disturbance to biodiversity and impacts related to traffic (AEA, 2012b).

In the first quarter of 2013, the European Commission organized a large consultation with citizens, organizations and public authorities about the development of unconventional fossil fuels (e.g. shale gas) in Europe[3]. Results of this consultation are feeding into the European Commission's "Environmental, Climate and Energy Assessment Framework to Enable Safe and Secure Unconventional Hydrocarbon Extraction." This initiative will aim at delivering a framework to manage risks, address regulatory shortcomings and provide maximum legal clarity and predictability to both market operators and citizens across the EU. It will include options for an impact assessment to prevent, reduce and manage surface and subsurface risks; to adopt monitoring, reporting and transparency requirements; and to clarify the EU regulatory framework with regard to both exploration and extraction activities.

Until the publication of this EU-wide risk management framework, and without clear policy direction from Brussels, the issue is in the hands of politicians in the member states, where political cultures vary considerably (Atlantic Council, 2011). Policymakers throughout Europe are already taking conflicting courses of action and some policy reversals have occurred. Most recently, the European Parliament voted narrowly (332 in favor, 311 against, 14 abstentions) for legislation that would require environmental impact assessments at all fracking sites as well as public participation activities. The final legislation needs to be worked out with the European Council, which represents the member states of Europe (Kanter, 2013).

In this political environment, it is not surprising that development of the European UG industry is slow (Buckley, 2012; Erlanger, 2013). To illustrate the different cultures and policies, we survey recent political developments in the UK, France, Germany, Poland and the Ukraine.

The United Kingdom

With a long history in oil and gas development (including use of advanced hydraulic fracturing technologies), significant potential UG reserves and a well-established regulatory system, the United Kingdom might seem to be a promising location for early UGD in Europe (Richards, 2012). This is certainly what private investors believed until an exploratory program by the firm Cuadrilla caused unexpected tremors (i.e. small-scale earthquakes) in Lancashire (north-western England). The UK Government responded in 2011 by implementing a temporary moratorium on all UGD until safety could be ensured (Herron, 2012).

In April 2012 a report by technical advisors to the UK Government confirmed the link between UGD and the tremors of 2011 but concluded that proper management of UGD could minimize any seismic safety risk (Green *et al.*, 2012; Royal Society, 2012). In late 2012 the government, not deterred by anti-UGD demonstrations in London and other cities in early December 2012 (Matlack, 2012), lifted the moratorium, arguing that properly utilized safety measures could reduce the risks of earthquakes to acceptable levels. The UK Government also emphasized that the spring 2011 tremors in Lancashire were not major damaging events, as the British Geological Survey had recorded nine tremors of similar magnitude in a recent two-month period with no harm to health and safety (Smith-Spark & Boulden, 2012). The UK safety proposal calls for a seismic survey before work starts, a plan for minimizing seismic risks (e.g. a regulatory system that stops development based on the magnitude of the induced seismic events) and regular monitoring of seismic activity before, during and after development (Smith-Spark & Boulden, 2012).

In December 2012, the UK Government announced that it has accepted all of the recommendations of the comprehensive and authoritative review of the risks of hydraulic fracturing as itemized in the Royal Society and Royal Academy of Engineering academies' report (Royal Society, 2012) and is now working to implement their recommendations (UK, 2012).

Recommendations include:

- A "frac plan" will need to be constructed, submitted and approved by the Department of Energy before any development activity can be initiated.

- An environmental risk assessment (ERA) will be mandatory for all shale gas operations and involve the participation of local communities at the earliest possible opportunity. The ERA should assess risks across the entire life cycle of shale gas extraction, including the disposal of wastes and well abandonment. Seismic risks should also feature as part of the ERA.

- A transparency requirement: all baseline monitoring data will be uploaded on operators' websites for public use. This goes beyond the current transparency in UGD debate in many countries, which is limited to only disclosing the ingredients of fracturing fluids.

[3] Results of the consultation are available at: http://ec.europa.eu/environment/integration/energy/pdf/Presentation_07062013.pdf

The UK is also establishing a new Office of Unconventional Gas to provide strong regulatory oversight and to resolve disputes between developers, consumer and environmental groups, and local communities. Tax incentives to encourage shale gas development in the UK are also under consideration (Alterman, 2012; OGJ, 2012; S. Williams, S., 2012). The UK Government's new pro-UGD policy has already stimulated some new private-sector interest, but the industry in the UK is expected to grow slowly (Young, 2013).

The NGO "Frack Off" opposes any fracking in the UK and is arguing that severe health effects are beginning to occur in areas of the world where shale gas extraction is widespread (Scott, 2013). The Church of England is also raising concerns. The Diocese of Blackburn (UK) is issuing leaflets that highlight the environmental downsides of fracking and the Christian duty to be "stewards of the earth" (Kirkup, 2013). In West Sussex, up to 1,000 demonstrators set up a tented camp in the summer of 2013 to protest against drilling at one of the first rigs. More than 100 people were arrested, including a Member of Parliament from the Green Party. The company elected to remove the test rig (Erlanger, 2013).

Unlike in the US, in the UK the state owns the mineral rights. However, the national government and industry are willing to authorize some compensation to go directly to local communities rather than exclusively to the central government. The industry has published a community engagement charter (UKOOG, 2013), which includes local incentives. One company is offering local communities in the UK US$151,000 for each well site, plus 10% of any resulting revenues (Reed, 2013). In June 2013 the Department of Energy and Climate Change (DECC) announced that communities that sign up to host shale gas drilling sites will also be rewarded with tax incentives.

The UK is thus moving proactively to address many of the controversial aspects of UGD by presenting numerous specific options. Progress toward actual exploration and production of gas is slow.

France

From a geological perspective, UGD in France is attractive because the country has some of the richest shale deposits in Europe. As of early 2010, the Conservative government led by President Nicolas Sarkozy appeared to be receptive to the development of this new industry.

In March 2010 government officials in south-east France awarded three shale gas exploration permits, two to the Texas-based company Schuepbach Energy and one to the Paris-based multinational Total SA. Later, the firms Mouvoil SA and Bridgeoil SAS were also awarded permits in southern France (Patel, 2011). Meanwhile, Hess Oil France was partnering with the French firm Toreador Resources to explore for oil and gas in the Parisian basin (Jolly, 2011). Some of the permits, which ranged in duration from three to five years, were for research only. In the latter case, the necessary permit and authorization to proceed was not obtained from the state to operate a concession for field activities and production.

The organized environmental movement in France responded quickly and aggressively. Friends of the Earth issued a public statement that the precautionary principle should be applied to UGD, including a comprehensive environmental and health impact study (FOE, 2012). An elected French representative to the EU with strong ties to the Green Party, José Bové, organized a press conference where he urged local communities in France to ban exploration activities at the municipal level. Administrative appeals were filed in south-east France against the permit that was granted to Total SA (Zarea & Waz, 2012).

The French Government is designed to hear the concerns of citizens, as the 22 regions of the country are each divided into *départements*, *arrondissements*, cantons and communes. Communes can organize public consultations in which issues of concern are discussed, and "fracturation de la roche" quickly became one of them (Mansfield, 2011).

The 2010 documentary film "Gasland," which features the alleged environmental problems associated with shale gas in the US, was shown on national television in France on channel Canal+. Excerpts from "Gasland" were also shown to citizens at local town meetings, as environmental activists made their case that France should not permit UGD like the US does, at least not with "fracking" (Mansfield, 2011). As opposition to UGD was building in early 2011, news from the United States included the revelation that diesel fuel was being used as a drilling fluid in some fracking operations (Rascoe, 2011).

The focus of the French opposition to UGD was not earthquakes, as in the UK, but a concern about the potential for contamination of groundwater and ultimately drinking water with toxic chemicals (Reuters, 2011). Since the nascent UG industry was poorly organized and the French Government was slow to dispute the allegations or make the beneficial case for UGD, political momentum opposing UGD built quickly.

The palpable anger at ensuing protests went beyond what might have been expected from even a well-organized advocacy.

Citizens were shocked about the inadequate public notification of UG permits, the limited or non-existent public consultation in many communes, the alleged alterations of the mining code that had been made by government officials to facilitate UGD, and the implication that the natural resources of France would be subjected to American-style energy production practices. The resulting rallies and protests across France, including hundreds of anti-shale "collectifs," did not take long to reach the political leaders of France (Mansfield, 2011).

The response of the Sarkozy government, which was facing elections in May 2012, was hardly reassuring. The former ecology minister under Sarkozy, the official who signed the initial UGD permits, was confessing a mistake and helping efforts to design a stricter regulatory system. In February 2011 the prevailing ecology minister under Sarkozy ordered a temporary moratorium on shale gas development (Jolly, 2011). The minister went further to explain that hydraulic fracturing is the only known technology that can access shale gas but it is "not something we want to use in France." When pressed to explain why a moratorium was not placed on all shale gas activities, the minister stated that the "current mining laws do not permit it (a moratorium)" (Platts, 2011).

By the end of 2011, drilling near the town of Villeneuve-de-Berg in southern France was scheduled to begin. In March 2011 well-organized protests involving more than 20,000 people occurred in Villeneuve-de-Berg (McKenna, 2011).

The Sarkozy government enlarged the moratorium to cover research permits and any new UGD permits while extending the moratorium until June 2011, when an environmental study was scheduled for completion (Leblond, 2011). This stance was too weak in the eyes of elected officials in Sarkozy's own party, and the French National Assembly took the issue into their own hands (Jolly, 2011).

Legislators from Sarkozy's Union for a Popular Movement (UMP) party proposed legislation that banned hydraulic fracturing and revoked existing shale gas permits. The bill did not rule out research into ecologically superior methods of UGD. Joining the opposition to UGD, Sarkozy insisted that the desire to tap new energy resources could not justify "massacring an almost spiritual landscape" (NewEurope, 2011). The Socialist Party argued that the UMP bill was full of ambiguous language that might permit some use of hydraulic fracturing in the future and was too permissive of other types of UGD (Pilgrim, 2011).

Through rapid actions of its National Assembly, France became the first country in the world to ban hydraulic fracturing for oil and gas production. The key vote in the Senate was 176 in favor, 151 against, as the opponents – predominantly the Socialists – argued that an even stricter ban should have been enacted (Patel, 2011; Scolnick, 2011). Some companies[4] challenged the constitutionality of the prohibition through litigation but the prohibition was upheld by the French judiciary (Jolly, 2013).

In his ultimately successful bid for the French presidency, Socialist Francois Hollande took a firm campaign position against UGD. But the proponents of UGD were not deterred. After the May 2012 election, a coalition of energy companies and labor unions sought to persuade the Hollande government to permit limited UGD under strict regulations. Their case was boosted when a report commissioned by the French government and chaired by Louis Gallois, former chairman of EADS, concluded that shale gas development could be a significant boost to France's sagging economy (Amiel, 2012).

In September 2012, Hollande seemed to close the door on any form of UGD: "As far as the exploration and exploitation of non-conventional hydrocarbons is concerned, this will be my policy throughout my (five-year) term of office." (Amiel, 2012). Hollande went further and explicitly instructed his environment minister to reject seven remaining applications for exploration permits, citing "the heavy risk to the environment." Thus, for the foreseeable future, France is not a hospitable legal or political environment for UGD.

Germany

At the request of the German Federal Ministry of Economics and Technology, the German Minerals Agency is undertaking an in-depth investigation ("Project Niko") of the extent of shale gas reserves in Germany, with complete results planned for 2015. Through periodic reports, this project is providing the most authoritative German view of the scientific issues (Petrow, 2012; Vinson & Elkins, 2013).

A recent report from the German Minerals Agency estimates that German shale gas reserves are in the range of 700 to 2268 billion cubic meters with minimal environmental risk from hydraulic fracturing (Bajczuk, 2013). The promising areas for development are located in the Lower Saxony Basin, which spans the states of Lower Saxony, North Rhine-Westphalia and Saxony-Anhalt.

Given that Germany has ambitious plans to reduce dependence on coal and nuclear power, an expanded role for natural gas has

[4] www.conseil-constitutionnel.fr/decision/2013/2013346qpc.htm

practical appeal, especially since a well-developed network of gas pipelines already exists and renewables are not falling in price as rapidly as required to meet Germany's long-term energy needs for affordable energy (Clark, 2013). Moreover, Germany is the largest importer of natural gas on the European continent and the third leading gas importer in the world. With roughly one third of those gas imports coming from Russia, there is also a security argument for a new UG industry in Germany.

Permits for natural gas production in Germany are issued at the state level, where there are 16 distinct agencies, but few permits have been issued to date due to concerns registered by environmental groups, community leaders and local politicians (Wüst, 2012). The website "Gegen Gasbohren" provides illustrations of the communications activities launched by citizens groups opposed to hydraulic fracturing. As of October 2012, the numbers of permits issued by state were: Baden-Wurttemberg (2, both now expired), Lower Saxony (5), North Rhine-Westphalia (19), Saxony-Anhalt (1) and Thuringia (2) (Petrow, 2012).

ExxonMobil was allowed to conduct three UG experiments (vertical stratigraphic test holes) in February 2008 at the "Damme 3," north of Osnabruck in northwestern Germany. The tests yielded positive results but no permits have been granted for gas production. The most recent new permit for UGD in all of Germany was granted in late 2011 (Wüst, 2012).

In Lower Saxony, where the permitting agency is based in Hanover, because of the shallow depth of the shale formation, there is concern about the potential for groundwater contamination. ExxonMobil has already invested US$26 million at a site in Lower Saxony ("Botersen Z11"), but has not yet persuaded the state agency to issue a permit for production (Wüst, 2012).

The situation in Germany is characterized by some features less emphasized elsewhere, and these are:

- A long tradition of geothermal research in Germany – consequently, the UGD and fracking are often tackled together with geothermal energy and by the same or similar stakeholders;
- The insurance "400 m limit" is often used to delimit "shallow" and "deep" drilling, each of them having in Germany different portfolios of priorities, in particular in terms of the protection against drinking water pollution;
- In terms of UGD, Germany is strongly divided north-south: the UG-rich north and the UG-poor south. This fact adds to the country's problems of unequal distribution of renewable and alternative energy and the respective issue of transmission; and
- The green certificate trading system in Germany has not yet been adapted to facilitate increased production and use of UG.

Box 4: Dialogue process on UGD in Germany

Natural gas has been exploited in Germany for more than six decades, and many municipalities have a perfectly harmonious relationship with the natural gas industry. However, this was challenged in 2010 when ExxonMobil and other oil and gas companies announced plans to use hydraulic fracturing in order to access natural gas reservoirs that had not up until this time been worth exploiting. This announcement provoked protests in many German cities. Fueled by US media reports, popular movements against hydraulic fracturing have sprung up in numerous places where exploratory drilling was planned. The main concern raised by the prospect of hydraulic fracturing was the risk of release of chemical and methane pollution into drinking water.

The German ExxonMobil affiliate ExxonMobil Production Deutschland GmbH (EMPG) has taken these concerns very seriously and popular opposition to hydraulic fracturing in Lower Saxony and North Rhine-Westphalia. The company realized it was necessary to respond to the concerns (and the attendant opposition), for unless these issues are addressed and an understanding is reached with the relevant stakeholder groups, exploitation would be difficult, even if all safety technical measures were taken. ExxonMobil decided to eschew the usual approach of going to court and lobbying legislators, and instead engaged in a process involving open communication and dialogue whereby independent scientists would conduct a study of the environmental and safety risks entailed by hydraulic fracturing. ExxonMobil asked two outside experts to develop a concept for this undertaking, accepted their proposed concept, and provided funding for a study by a panel of outside experts, as well as for a social dialogue. In April 2011, approximately 50 stakeholder groups (municipalities, citizens' action groups, church groups and associations) began participating in a dialogue process and monitored the work carried out by the panel of experts. The competent authorities from the German regional states of North Rhine-Westphalia and Lower Saxony acted as observers. The panel of experts was able to carry out its work without interference from ExxonMobil and in a transparent and open manner that met the highest scientific standards.

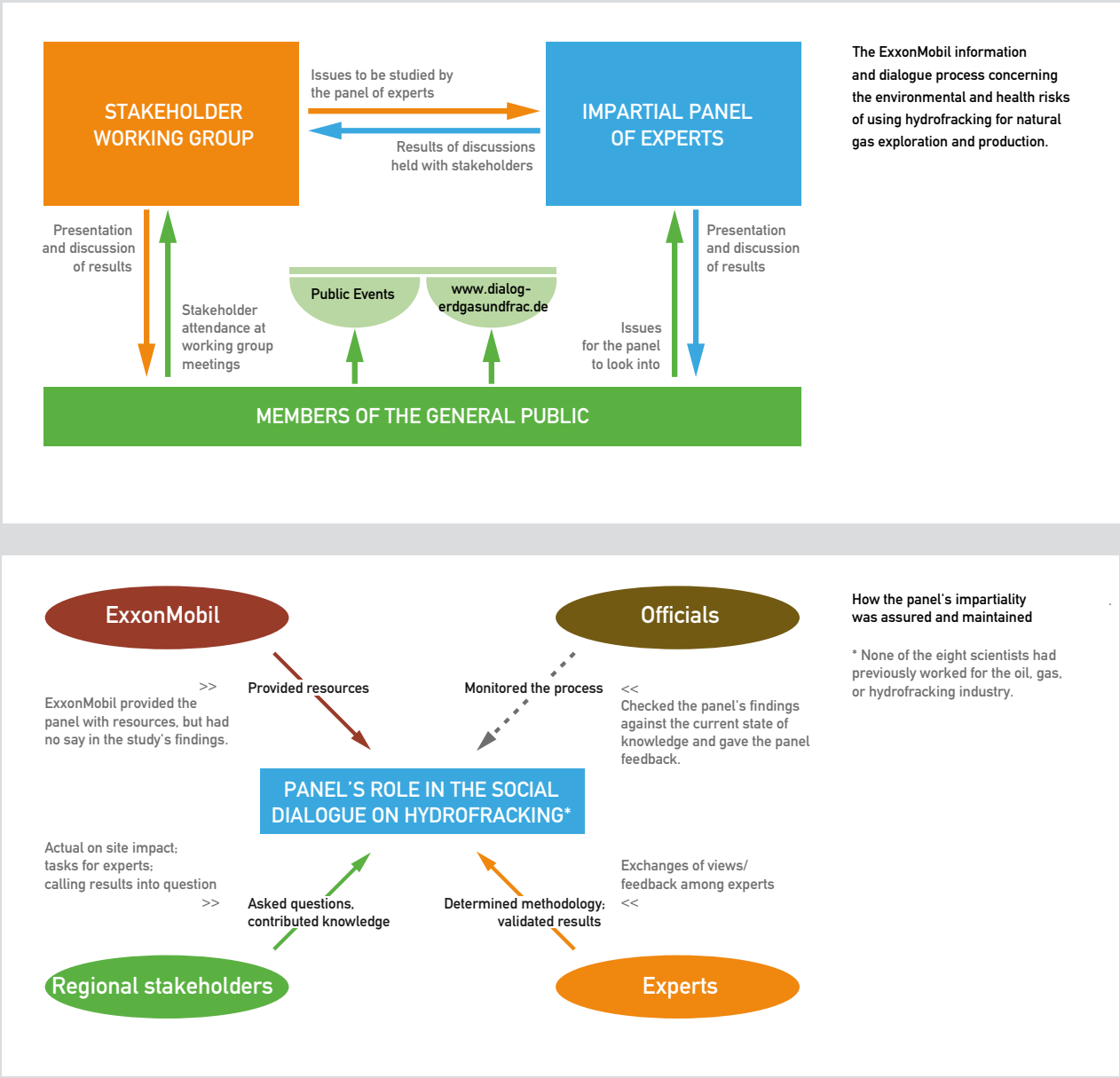

Figure 8. The dialogue process on UGD in Germany
Source: Ewen, *et al.*, 2012.

In September 2012 the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety issued a report recommending that, due to potential environmental risks, shale gas development in Germany should be conducted only on a limited basis and only under intensive administrative and scientific supervision. In January 2013, the Federal Institute for Geosciences and Natural Resources (Bundesanstalt für Geowissenschaften und Rohstoffe; BGR) developed an analysis for the Ministry of Economics. The analysis states that shale gas extraction using the hydraulic fracturing method does not pose an environmental threat (Karpia, 2013). In contrast, the environmental ministry in the German State of North Rhine-Westphalia, in collaboration with the Ministry of Economy, recommended a ban on shale gas exploration until safer drilling fluids and waste-disposal practices are developed. Soon after the report was released, the State of North-Westphalia prohibited hydraulic fracturing operations until the risks of the technology are better understood and addressed (Petrow, 2012).

Although the opponents of UGD in Germany achieved a de facto moratorium on permits at the state level, supporters of UGD warded off – at least temporarily – what happened in France: a national prohibition. In December 2012 Merkel's coalition government defeated motions from the Green Party and the Left Party calling for a prohibition on hydraulic fracturing. The vote margin was 309 against the prohibition, 259 in favor and two abstentions. A key argument made by defenders of hydraulic fracturing is that the technique has been used in Germany at conventional wells since the 1960s, with no documented groundwater risks or earthquakes. The German vote occurred the same day that the UK lifted its temporary moratorium on UGD (Nicola, 2012).

The Green Party, however, showed strength in the January 2013 elections in Lower Saxony, where the shale gas issue was hotly disputed by the Greens and Merkel's party. Since Merkel's Christian Democratic coalition lost by a single vote, the new government in Lower Saxony will be a coalition between the Green Party and the Social Democrats (Buergin & Parkin, 2013). With the recent re-election of the Merkel party, the federal government will have less pressure to soften their pro-UGD position.

The federal Ministry for the Environment, Nature Conservation and Nuclear Safety issued a draft ordinance on allowing UGD under certain restrictions for parliamentary discussion. The draft proposes alterations in the federal water law (no fracking in water protection areas) and environmental impact assessment (EIA) as standard when fracking is used. It is up to the political parties to launch a legal initiative in parliament.

Even if the environmental concerns about hydraulic fracturing could be addressed, the politics of UGD in Germany are complex. There are a variety of German business interests (e.g. the growing renewables industry) that see UGD as a threat to their commercial future (Vinson & Elkins, 2013). And the Russian firm Gazprom, the largest natural gas producer in the world, is believed by some analysts to have influential economic and political allies in Germany (Smith, 2012). Gazprom is closely tied to the Russian Government, which is publicly critical of efforts to develop an UG industry in Europe. Thus, for a variety of reasons, Germany appears to present an uphill battle for investors interested in unconventional gas development.

Poland

Poland has the largest deposits of shale gas in Europe. The estimated 5.3 trillion cubic feet of recoverable reserves in Poland are concentrated in the Baltic basin in the north, the Lublin basin in the south and the Podlasie basin in the east (Ernst & Young, 2012). Currently, Poland produces only about 29 percent of its annual gas consumption but the prospects of increasing domestic production are good through shale gas plays (Kruk, 2012).

The country's commitment to shale gas production arises from its 60 percent dependence on Russia for its natural gas needs, the prospects of a new domestic industry with employment and earnings, the opportunity to respond to the pressure from the EU to curtail its greenhouse gas emissions from coal burning, and the prospect of growing economic and political power in Europe (Kluz, 2012; Smith, 2012; Angleys, 2012).

Poland's President Bronislaw Komorowski began his 2010 presidential campaign with criticism of shale gas, but in a crucial presidential debate, argued that shale gas should be explored as an alternative to a new 20-year gas deal with Russia (NGEurope, 2010]). After becoming president, Komorowski has offered strong support for shale gas, from seeking cooperative technology efforts with the Obama administration to requesting new legislation that will provide a favorable investment climate for shale gas production.

Within the framework of a research project entitled "Assessment of environmental hazard caused by the process of prospecting, exploration and exploitation of unconventional hydrocarbons," the Director General for Environmental Protection commissioned an analysis of the environmental impact of operations related to prospecting, exploration and exploitation of shale gas in selected wells. The work was carried out by a consortium composed of the Polish Geological Institute – National Research Institute (leader), University of Science and Technology and Technical University of Gdansk.

Several public opinion surveys were conducted in Poland in 2011–2012, one with a focus on the Pomorskie region of Poland where UGD is under way. A large majority of respondents favor shale gas exploitation, less than 5 percent are opposed and about 23 percent are undecided (Burchett, 2012). Opposition is somewhat greater if a well is located in the neighborhood where the respondent lives. However, within Poland there remains concern about the objectivity of a survey conducted by the European Commission on public sentiment toward UGD[5].

[5] http://www.lupkipolskie.pl/aktualnosci/newsy-ze-swiata/02-2013/ankieta-w-sprawie-gazu-lupkowego-powinna-byc-powtorzona

The Polish Government has already issued more than 100 shale gas exploration licenses to Polish and international companies and smaller independent firms (Elliot, 2012). Despite a favorable political climate, the UG industry in Poland has not grown rapidly. A variety of setbacks has slowed progress and compelled the government to start work on an entirely new regulatory framework for the industry.

The setbacks began with a realization that the initial recoverable reserve estimates published by the United States Government were biased upward, though updated estimates of reserves are still quite substantial. Poland's antiquated leasing process was also ill equipped to handle the surge of interest from firms. Some of the initial wells delivered relatively little gas production, which helps explain why ExxonMobil decided to leave Poland in 2012 (Cienski, 2012). Investors lack certainty about how much the government will tax revenues from gas production, and Poland lacks accounting guidance for how joint operations with foreign partners should handle finances (Ernst & Young, 2012). Municipalities and local governments questioned what benefit they would reap from the new industry.

For several years the Polish Government has been developing a much anticipated new law that will provide greater regulatory clarity and certainty for investors, including a uniform system of concessions and taxes. The growth of Poland's UG industry will be slow until the new law is finalized, since many investors will remain cautious until the details of the regulatory system are known (Burchett, 2012; Scislowska, 2013).

Concession holders had drilled around 50 shale gas wells by August 2013. This number is still the largest number of wells in Europe even though it is less than previously assumed. In the upcoming years, up to 350 wells might be drilled, according to Polish concessions. Lower assumptions of the recoverable gas resources published by the Polish Geological Institute in March 2012[6] cooled down industry optimism a little, but it did not result in companies withdrawing. A few companies resigned from shale gas prospection in Poland, but their concessions were bought by others which are proceeding with development.

Right now the government is finalizing public consultations on the new regulations planned to be implemented as soon as possible to enable companies to plan their activity. Until the new law is implemented, a slowdown of shale gas exploration is expected.

Ukraine

Ukraine has Europe's third largest shale gas reserves at 1.2 trillion cubic meters, behind those of France and Norway. Ukraine deals currently with Royal Dutch Shell and Chevron for shale gas development, while paying the extremely high price of over €300 per thousand cubic meters for Russian gas under a 10-year deal signed in 2009 by a preceding government.

Chevron has proposed investing over €250 million in initial tests to ascertain the commercial viability of gas deposits at the Olesska field, with a further investment envisaged for the first stage of extraction. According to EurActiv (www.euractiv.com), Chevron, on one side, claims to be addressing the concerns raised by the Ivano-Frankivsk Regional Council, where the representatives of the far-right nationalist opposition claim that the agreement opens the way to lawful destruction of Ukrainian land during gas extraction and turning hundreds of kilometers of Ukraine into swamp and desert. Chevron would have the right to use sand, stone, underground water supplies and other water sources on the basis of agreements in and beyond the (agreed) area.

The shale gas plan in Ukraine hit a setback in August 2013 when a local council rejected the government's draft production-sharing agreement with US energy company Chevron amid warnings by nationalists regarding likely damage to the environment. The deputies in Ivano-Frankivsk region, in western Ukraine, had sent the draft back to the government, pressing for guarantees which would address their concerns over the exploration plans. Chevron wants to finalize a deal to explore the Olesska shale field in western Ukraine. Both the population and some politicians are concerned that the ecological consequences of shale exploration in the mountainous forested region could affect the region known for its inland tourist resorts. But the government sees shale gas development as important for easing its dependence on costly gas imports from Russia, which weigh heavily on its economy.

[6] http://pgi.gov.pl/pl/dokumenty-in/cat_view/294-aktualnoci-2012/297-zasoby-gazu.html

Box 5: European public opinion about unconventional gas development

Between December 2012 and March 2013, DG Environment organized a large consultation among the European population (individuals and organizations) to collect information about public opinion and recommendations about the development of unconventional gas in Europe.

The majority of respondents came from France, Germany, Poland, Romania and Spain. Poland is the only country with a majority of respondents in favor of UG development. These results are consistent with a Eurobarometer study, conducted in January 2013 among 25,000 people, which revealed that the majority of Europeans would be concerned if shale gas projects were located in their neighborhood:

- 74 percent of survey respondents said they would be concerned, of which 40 percent said they would be very concerned (ranging from 54 percent in France and 52 percent in Austria to 16 percent in Poland and Hungary);
- 20 percent would not be too concerned, of which 7 percent would not be concerned at all.

A majority of respondents in the public consultation sees opportunities for the EU economy (to create employment, attract investment and enhance competitiveness), industry, technological innovation and energy security (to avoid increasing the EU's energy import dependency, strengthen the negotiation position towards external energy suppliers, help diversify the EU energy mix and make energy cheaper for consumers).

Europeans are concerned primarily about the following aspects related to UG development:

- New problems related to water quality and quantity;
- Potential land, soil and biodiversity issues (habitat fragmentation, reduction of agricultural land);
- Geological issues (seismicity);
- Lack of transparency and public information;
- Lack of capacity of public authorities to supervise a large number of facilities;
- Potential legal and political failures (fragmentation of regulation, inadequate legislation applicable to UG projects and inconsistency in application of regulation); and
- Potential lack in technology knowledge (in particular about the hydraulic fracturing process).

They are also concerned about decommissioning after operations cease (decontamination and rehabilitation of the site).

Asia

Throughout Asia, where the price of natural gas is much higher than it is in North America, countries are pursuing a wide range of policies to address the unmet demand for natural gas. These policies include construction of new pipelines to deliver imported gas from other regions, importation of LNG by ocean vessels, greater development of domestic UG resources and pursuit of alternatives to gas (coal, nuclear and renewables). China and India have expressed a particular interest in UG development but, as we explore below, a lack of infrastructure and trained workforce will slow the development of their industries.

China

China is estimated to have the largest deposits of shale gas in the world. According to official US Government estimates, China has technically recoverable shale gas resources roughly equivalent to what is available in Canada and the United States combined (Nakano *et al.*, 2012) and efforts are currently under way to better evaluate both the technical and economical recoverability of those resources. China has not yet launched large-scale commercial production and does not yet have a coherent regulatory policy, but there are clear signs that China intends to develop an UG industry (Nakano, 2012; Biswas & Kirchherr, 2013). Some analysts see UGD in China as crucial to slowing an environmentally destructive rate of increase in coal dependence (Muller, 2013).

In March 2012 China released its first five-year plan for UG development. Goals have been set for producing 6.5 billion cubic meters of gas by 2015, rising to 100 billion cubic meters by 2020 (Nakano *et al.*, 2012; Biswas & Kirchherr, 2013). As of late 2012, Chinese companies had drilled 61 exploratory wells (horizontal as well as vertical), of which 21 were generating gas. Four particularly favorable areas (Weiyuan, Changning, Zhaotong and Fushun-Yongchuan – in South Sichuan and North Guizhou) have been selected for initial production (Jianzhong, 2012).

In early 2013, the Chinese Government finalized the assignment of new blocks of land for shale gas exploration. Although the Ministry of Land and Resources attracted few investors in a first round of bidding (2011), the second round (October 2012) led to US$2 billion in commitments over the next three years in 19 different blocks (BNN, 2013).

The ministry has pledged to supervise the work of the 14 winning bidders (all Chinese firms), making sure that the work is carried out as promised. International energy companies were excluded from the bidding, though they are looking for a variety of ways to become involved in the years ahead, through partnerships with Chinese companies.

New Chinese policies to accelerate the pace of UG production have been enacted or are under consideration. For technologies that are imported to China to assist in UG production, import taxes will be reduced or waived (Nakano *et al.*, 2012). Prospecting and mining royalties may be waived and value-added taxes reimbursed. And production subsidies, already in place, range from 3 to 5 cents per cubic meter of gas produced.

China's environmental regulatory system is not well developed, though they have relevant experience through regulation of coal bed methane production (Nakano *et al.*, 2012). The Chinese Ministry of Environmental Protection has issued standards to minimize methane emissions. The other ministries likely to be involved in shale gas development are less focused on environmental protection. They include the National Development and Reform Commission, the Ministry of Land and Resources, the Ministry of Finance and the National Energy Administration (Nakano *et al.*, 2012).

Inadequate water supplies may slow the rate of growth of China's UG industry. Eight of China's 10 river basins are projected to experience water shortages by 2030. Some of the most desirable shale-gas opportunities are located in basins that are already facing acute water shortages.

Shell has taken a particular interest in China's shale project. The company's progress has been slowed by difficult geology, dense population centers, uncertain regulatory regimes, controlled gas prices, and complaints in villages near drilling sites due to monetary compensation issues (Zhang, 2013). The central government of China is working to help address Shell's concerns.

In December 2011 the Chinese government signaled a shift toward more market-based pricing of natural gas, including an experiment with pricing reform in Guangdong province and the Guangxi region. The long-term plan is to liberalize wholesale well-head prices for unconventional gas resources, including shale gas, coal bed methane and coal gas (Nakano *et al.*, 2012).

Bilateral shale gas cooperation was established in 2009 as a US-China priority by presidents Obama and Hu. The US-China Shale Gas Resource Initiative covers resource assessment, technical cooperation, investment promotion, study tours and workshops (White House, 2009). Given this level of presidential interest in China, it is likely the country's commitment to shale gas will rise rapidly in the years ahead (Nakano *et al.*, 2012).

India

Natural gas production in India is rising more slowly than the rise of domestic consumption, causing a growing dependence on gas imports (Nakano *et al.*, 2012). Shale gas production is seen as a long-term strategy to curtail import dependence, as India is estimated to have 63 trillion cubic meters of technically recoverable shale gas resources.

Promising locations include Barren Measure Shale at Icchapur near Durgapur in West Bengal plus reserves in Cambay, Kaveri-Godavari, Cauvery, Indo-Gangetic and Assam-Arakan basins (Nakano *et al.*, 2012). The Damodar Basin is considered particularly promising because coal bed methane operations are already under way, the shale is relatively shallow, and nearby water resources are plentiful.

Currently, India has no large-scale UG industry and no established regulatory framework. A first round of exploration licensing, set for late 2011, was postponed at the insistence of the Ministry of Environment and Forests due to lack of adequate environmental assessments. Even if production were to increase rapidly, progress would be slowed by the lack of adequate main transmission pipelines and tie-lines. A shortage of personnel with training and experience in energy production is an acute problem (Ernst & Young, 2013).

Nonetheless, former Indian President Pratibha Devisingh Patil told the Parliament that shale gas exploration and production are a priority. A proposed regulatory framework, including fiscal incentives for developers and market-based pricing of gas, has been issued for public comment (Ranjan, 2012; Telegraph, 2013). A "Shale Gas Work Plan" devised by officials from India and the United States calls for cooperation on resource assessment, training of Indian nationals and joint publication of shale gas studies (Joint Statement, 2012; Shastri, 2012). And India has also developed a bilateral cooperation agreement with Canada.

Recommendations

The challenge for political officials around the world is to determine whether development of an UG industry is in the interests of their constituents and, if so, what type of risk governance system should be instituted. The success of UGD will not be determined solely by technical and economic factors. Unless UGD is perceived to be legitimate by political officials and acceptable by their constituents, UGD will not be sustainable. Based on the political histories in this report and IRGC's experience with other technologies, IRGC suggests the following guidelines for countries expanding or considering UGD.

1. Legitimacy of UGD will be easier to accomplish in some jurisdictions than others, depending on factors such as the degree of citizen familiarity with oil and gas development, the perceived need for industrial employment, the intensity of organized opposition to UGD, the presence of a strong regulatory program that the public trusts and the jurisdiction's degree of commitment to competing energy sources (e.g. renewables).

2. Local community opposition to UGD is likely to be formidable if a strong and trusted regulatory system is not present, if concerns about safety and environmental risks are not addressed effectively, if new contributors to traffic and congestion are not addressed properly, if local communities do not receive financial benefits from UGD and if permitting procedures fail to provide early citizen notification and ample opportunity for community deliberation.

3. In order to sustain political legitimacy, a strong public sector risk governance system built on the principles of sound science and data verification is critical. Government officials should expect significant activism for and against UGD, coupled with heightened media coverage and citizen interest. When unfounded claims (pro and con) are made about UGD (e.g. in the media), the response from government officials must be timely, authoritative and responsive to the key issues.

4. Successful development of UG resources requires large investments in related infrastructure (e.g. pipelines, processing and – if overseas exports are envisioned – LNG export terminals) that are unlikely to be accomplished without active support from political leaders at multiple levels of government and in competing parties.

5. Success in UGD can occur rapidly under the right conditions but it will not occur without a systematic and sustained commitment to the necessary capabilities (e.g. technological, workforce, infrastructure and communications). At the community level, UGD will also require additional resources for local and regional planning, water authorities, roads, schools, healthcare facilities and other inputs to daily life.

6. Countries without strong track records in oil and gas development should consider cooperative efforts with experienced countries in order to facilitate understanding of complex issues ranging from geology and drilling technology to regulatory systems and local community participation.

7. To foster trust in the global UG industry, energy companies around the world should consider developing, on their own, a program like the chemical industry's "Responsible Care," which ensures best practices of risk management, sustainability and community engagement are followed. A consistent standard of industry care may buttress public trust in UGD, especially in situations where regulatory agencies are not trusted due to underfunding, lack of expertise or other organizational factors.

Section 4:

The evolution of regulatory systems for UGD

Introduction

No new energy technology springs forward immediately with a perfectly formed, comprehensive and fine-tuned regulatory system – regulatory systems evolve. The governance of risks associated with UGD has therefore evolved as a country or state/province develops experience with gas exploration, development, production and closure, and in response to challenges or problems that are specific to that region. In Texas and Alberta, for example, the regulatory systems for UGD evolved directly from a well-functioning regulatory system that was already operating for conventional oil and gas projects.

A variety of problems can occur in the evolution of regulatory practice. Some jurisdictions may restrict or prohibit UGD before the industry has a chance to develop and the public has a chance to become familiar with the industry. That is what has happened in France, Quebec and the State of New York. On the other hand, the rapid pace of UGD in a region may overwhelm the applicable regulatory system, as seems to have occurred in Pennsylvania and could happen in Poland or the Ukraine. When development of the regulatory system is too slow (e.g. due to insufficient public investments in competent personnel to review permit applications and inspect drilling sites), the public may lose confidence in the regulatory system, especially if highly publicized adverse incidents stigmatize both the industry and regulators. Investors may also lose confidence, as a competent regulatory system may be necessary to reassure investors in the sustainability of UGD.

Since regulatory systems for UGD differ and are at different stages of evolution, they can be quite confusing for policymakers and regulators in jurisdictions that have little experience in oil and gas oversight and do not have an established and well-functioning regulatory system. These jurisdictions may wish to be responsive to concerns about environmental protection, community values and industry needs, but are not clear about what regulatory systems best ensure such responsiveness.

In this section, the IRGC pinpoints some of the key components of an effective regulatory system for UGD. Effectiveness implies minimization of health, safety and environmental risks without crippling the ability of developers to engage in UGD. While effective regulation may also attenuate public concerns, it cannot resolve all of them. Like all forms of energy production, UGD is not risk free, even when it is overseen by an effective regulatory system. Thus, politicians need to appreciate that UGD will stimulate some public controversy, even if the activity is properly regulated.

This section begins by defining some key terms. This is followed by an exploration of why regulatory systems vary, and what is different about UGD that may trigger modernization of a jurisdiction's regulatory system. The key components of a comprehensive system are then described, all rooted in the importance of a site-specific operating permit with binding conditions that constrain the behavior of developers. The section follows with a discussion of the essential role of stakeholder participation in both the design of the regulatory system and the process of issuing site-specific permits. We conclude with recommendations about the design and refinement of regulatory systems.

Defining key policy instruments

The term "regulatory system" is used broadly here, referring to a wide range of different types and combinations of policy instruments, direct government regulation of industry in the form of standards, including liability systems under common law, and economic incentives to reduce risks through application of bonds, taxes and subsidies. Direct government regulation, through the imposition of mandatory standards, is by far the most common regulatory instrument in the oil and gas sector and may be the easiest to incorporate into existing regulatory systems.

In theory, the multiple potential risks of UGD could instead be regulated through lawsuits where those damaged by development activities sue for compensation from developers in courts. The liability system would provide an economic incentive for risk management, and the policies toward damage awards could be tailored to optimize the incentives for risk management. Although liability systems are sometimes employed as a supplement to direct regulation of UGD, we found no political jurisdiction that relies entirely on a liability system to regulate UGD. Presumably, the transactions costs in a liability system would be fairly high, and it is hard to imagine the public having confidence in UGD without any direct regulation.

Economic-incentive instruments are sometimes recommended as an alternative to direct regulation of risk-generating activities. One could envision taxes or fees applied to some or all of the risks associated with UGD. Certainly some of the pollutants from

UGD (e.g. methane) could readily be included in a cap-and-trade program to control pollution (e.g. greenhouse gases) from multiple industry sectors. Nonetheless, we found no jurisdiction that relies entirely on economic incentives to manage the risks of UGD, possibly because direct regulation is more familiar to policymakers and is more reassuring to people concerned about the potential risks of UGD.

The essential component of a direct regulatory system is an operating permit. Permits specify the conditions of operation that constrain the behavior of the developer in ways that protect human health, safety and the environment. The conditions of operation are typically compliance with mandatory design, performance and/or process standards. A necessary facet of direct regulation is a system of inspection and enforcement, including adequate resources for permit review, inspection of specific sites, and some form of penalties against developers who violate the conditions of their permits.

Regulatory systems for UGD do not exist in legal isolation. As systems are established and refined, the governing body – whether comprised of groups of elected officials, political appointees or career civil servants – must make decisions that situate regulation of UGD within an existing system of public law. The regulatory system cannot be properly designed without some appreciation of the technical and financial capabilities of the industry and the regulatory entity that will oversee the industry's operations.

Ideally, the regulatory system for UGD will reflect espoused energy policies. If a country is determined to replace coal with natural gas in many applications, then the regulatory system for UGD will need to facilitate development of the industry. If a country prefers reliance on nuclear power and renewables compared with gas, then a highly stringent regulatory system for UGD may be appropriate. Consequently, some jurisdictions will design their systems to give more weight to protecting health, safety and the environment, while others will favor industrial development.

A regulatory system is embedded in the larger political/legal system that defines property rights. Political systems vary in whether mineral rights are publicly or privately owned, and such variability may affect the assignment of rights and the allocation of authority within a regulatory system. Stakeholders may be defined differently depending on whether the resource is public or private. Many of the affected resources are privately owned in North America but publicly owned in many European countries. Therefore, in the United States the consent of a landowner may be necessary to undertake UGD while in some parts of Europe the consent of the municipality or other public authority may be determinative.

How and why regulatory systems vary

The traditional regulatory system may be part of a broader regulatory scheme covering all oil and gas (or even all mining activity), or it may be tailored specifically to oversee only specific technical aspects of UGD, such as hydraulic fracturing and horizontal drilling. It is essential for policymakers to analyze the existing regulatory framework to determine current assignment of authority and responsibility, and then to determine if there are any regulatory gaps for UGD that need to be closed. In some cases, a history of development of another mineral resource within a given jurisdiction may aid the governing body in the development of governing mechanisms for UGD.

Regulatory traditions tend to reflect the values that are important to people in a particular region. Jurisdictions may place priority on certain elements within their regulatory system based on factors like population density, distinct aesthetic or community character, proximity to rivers and lakes, and other special environmental resources. On the other hand, some essential resources, such as drinking water and air quality, will always give rise to public concerns if it becomes apparent that UGD is a threat to those resources.

In countries with multiple levels of government, regulatory systems could have national authorities provide minimum levels of regulatory protection ("floors") but allow states/provinces and localities to go beyond the floors if they wish. Alternatively, national regulatory systems can pre-empt state and local regulatory actions, and state/provincial authorities can serve as the primary regulators (instead of the national government) and permit or prohibit additional regulation by local governments (so called "primacy" arrangements).

The case for national regulation is stronger when there are large interjurisdictional externalities (i.e. one state/province is polluting the air or water of other states) and/or when there is evidence that competition for industry could lead to a race-to-the-bottom in the amount of regulatory oversight provided by states/provinces. Opinions vary as to whether these conditions are applicable to UGD.

Real-world oil/gas regulatory systems differ in how much authority is allocated to national, state/provincial and regional/local regulatory bodies. Insofar as the objective is competent and trustworthy regulation, it is important that the authority be assigned to a governmental unit with the resources and expertise for effective regulation, and the credibility to meet the public's and industry's expectations for competence. The location of such governmental units may vary from country to country.

Should there be a consistent national regulatory program or is it preferable to have a state or provincial approach that is tailored to a region's geology, community values, and industrial capacities? States ("states" in the US or "provinces" in Canada and other nations) and industry are often proponents of state-level controls, citing the greater resources, expertise and information in the states, more responsiveness to public and industry concerns, and compatibility with historical land use. Alternatively, environmental entities often argue that a uniform national ("at country level," i.e. federal in the US or nations in Europe) regulatory system can better ensure implementation of the technical standards that are required to protect public health, safety and the environment. In other words, a uniform national system of UGD regulation may better ensure minimum safeguards for public health, safety and the environment than a system that relies entirely on state/provincial regulation.

Industry will tend to favor regulation when the regulators are responsive to industrial interests, but industry views are not monolithic. Firms that are leaders in health, safety and environmental protection may prefer strict safety standards applicable to all firms, in part to increase the production costs of rivals but also to avoid accidents by unscrupulous firms that could damage public support for all firms in the industry. Small firms are often quite innovative and they have been crucial to the development of the UG industry but those same small firms may lack the staffing and infrastructure to deal with complex regulatory systems at multiple levels of government. Larger, more established companies – which sometimes purchase the smaller yet innovative firms – are generally in favor of regulation if it is based on science and industry best practices. Additionally, industry is often in favor of "regulatory certainty". When companies are considering where to do business, those jurisdictions that demonstrate well-functioning regulatory systems are preferred, even if the system may appear stringent or burdensome as its predictability and credibility are highly valued by developers.

For many, if not most jurisdictions, the assignment of general governance authority and responsibility is already established. In North America, where states or provinces are the primary regulatory authorities, UGD is exempt from several national environmental statutes. Sometimes state or provincial regulation fills gaps in national authority. In general, when states or provinces operate under national regulatory regimes, they may be afforded some flexibility to tailor the associated rules and regulations to their state's needs and preferences.

Similar arguments are often cited in the policy debate about the extent of state versus local governance authority. Local governments often argue that their traditional land use authority and their high responsiveness to local concerns should outweigh increasing state control over UGD. A counter argument is that local control creates a patchwork quilt of regulations that increase compliance costs for industry and may create a disparate impact on disadvantaged communities, especially where local government is dysfunctional or lacks technical expertise in UGD. As a result, the different levels of government may compete for regulatory power over UGD, with the location of power shifting over time in various jurisdictions.

Because oil and gas development practices are location specific, regulatory systems tend to be oriented to the issues that arise with a particular subsurface geology and the related surface conditions and activities (Koppelman & Woods, 2012). The approximate depth of the Eagle Ford Shale formation in South Texas ranges from 4,000 to 12,000 feet, with the shale located predominantly in rural areas of low-population density. The Barnett Shale is located between 6,500 and 8,500 feet below the surface and underlies suburban Fort Worth, Texas, where the population is almost 750,000 citizens. In contrast, both the Antrim Shale in Michigan and Illinois's New Albany Shale have depths ranging from only a few hundred feet to 2,000 feet below ground. Different regulations and safeguards are required in different geological and geographic settings. In Texas, for example, the Railroad Commission has created some rules that are unique to specific gas-producing fields or regions, and municipalities in Texas have authority to establish setback requirements and well distances from commercial buildings, public parks and residential homes.

Differences between regulatory systems are influenced not only by geological factors, but also by variability in the overall value of oil and gas reservoirs and the distribution of ownership of those resources. Moreover, regulatory systems may reflect the extent of a pro-safety culture among developers who have operated in an area, with a history of "bad actors" generally causing more stringency in the design of the regulatory system.

The relationship between developers and nearby communities will also vary enormously and is influenced to some degree by the design of the regulatory system. What is expected of a developer, in terms of community engagement, may vary depending on:

- Population density of nearby communities;
- Sophistication of the community governance systems;
- Maturity of the development;
- Community norms related to extractive industries; and
- Ownership of the mineral rights or impacted natural resources like water, and other factors.

Even if a regulatory system does not compel specific forms of community engagement, the informal regulatory system will look for evidence of community engagement.

Therefore, it should be expected that regulatory systems for UGD will vary. Any new or modernized regulatory system will not necessarily be a carbon copy of another jurisdiction's system.

Box 6: Pennsylvania "scrambles" to address wastewater disposal issues

The State of Pennsylvania developed its own UGD environmental regulations because the oil and gas industry is exempted from several federal environmental laws. This has resulted in a pattern of state regulators reacting to crises rather than anticipating and preventing them. The disposal of contaminated wastewater from UGD is a case in point.

UGD often generates a significant amount of wastewater, particularly when high-volume hydraulic fracturing operations are used, or if UG operations intersect brine-producing formations. The wastewater, along with the gas from wells, may contain some of the chemicals found in the fracturing fluid, as well as metals from the formation and high concentrations of total dissolved solids (TDS), mainly salts and minerals. In Pennsylvania, questions about the industry's management of wastewater grew with the rapid pace of drilling in the region.

The industry had experience elsewhere injecting the wastes into deep wells or evaporating them, but neither is feasible in Pennsylvania because of its geology and climate. To determine how to properly manage and safely dispose of the generated waste, mistakes were made that harmed the environment, allowed for unsafe water to be delivered to homes, damaged the credibility of the regulatory system and contributed to a poor perception of the industry.

The flowback and produced water from shale gas production in the Marcellus Shale has dissolved solids concentrations many times greater than the ocean, and thousands of cubic meters of wastewater may be generated from each well. Publicly owned treatment facilities were the first to accept the wastewater from the industry, and they did so for a nominal fee. Dilution of the pollution was the remedy, and this practice, a permit violation in some cases, did not draw the scrutiny of Pennsylvania's regulators for four years (Sapien, 2009).

In late 2008, regulators and the public began to pay attention after elevated concentrations of total dissolved solids were measured on the Monongahela River, a major tributary of the Ohio River (Hopey, 2008d). Industrial water users were the first to report high TDS concentrations in the river because of the corrosive effects on machinery. Citizens quickly followed as the drinking water supply for more than 350,000 people exceeded the US Environmental Protection Agency's drinking water standard for taste (Hopey, 2008c). It was debated how much of the fall 2008 spike could be attributed to the UG operations (Hopey, 2008b; Tetra Tech, 2009), but ultimately regulators decided to place voluntary limits on the brine disposal at these treatment facilities. These limits had immediate effects on UG operations and the economics of wastewater disposal for the industry (Hopey, 2008a; Sapien, 2009). TDS issues re-emerged in the Monongahela region the following summer (August 2009), and again there was wide disagreement about the origins of the pollution. Environmental groups mobilized following the water quality issues in 2008 (Hopey, 2008a), and plans were set in motion to effectively ban high TDS discharges to surface waters.

In September 2009, there was a major fish kill on Dunkard Creek, which lies on the border between Pennsylvania and West Virginia. More than 20 miles of stream were impacted by salt-loving golden algae toxic to aquatic species (Hopey, 2009b). Environmental groups labeled the fish kill a "crime scene," and there was again disagreement about the role of nearby UG operations in the fish kill. There is a long history of coal mining in the region, and mining was a known source of elevated TDS concentrations in the creek. The TDS spike that occurred prior to the fish kill and the source of the toxic green algae were investigated by the US Environmental Protection Agency and regulatory officials from both Pennsylvania and West Virginia (Hopey, 2009a). The natural gas industry denied any role, but in the spring of 2010 a widespread program of illegal wastewater dumping by a service company to the industry was uncovered, and the Dunkard Creek watershed was one of the disposal sites (Hopey, 2011). The illicit dumping revealed regular non-compliance with existing waste manifest systems that made it impossible for regulators to know if waste was being properly handled and disposed. Further, there continues to be speculation about the role of the shale gas industry in the fish kill (Soraghan, 2011).

As TDS issues emerged in 2008, so did concerns about the levels of bromide in surface waters (Handke, 2008). As water is disinfected, the bromide forms a disinfection by-product that is known to be carcinogenic. In summer 2010, water suppliers in the region began to measure disinfection by-

products in their water supplies at concentrations above US EPA limits. Many potential sources were investigated, but by 2011 there was conclusive evidence that bromide concentrations increased downstream of wastewater treatment facilities that were receiving wastewater from Marcellus Shale operations (States *et al.*, 2011; Johnson, 2013b).

Faced with this evidence, state officials decided to request that Marcellus Shale operators voluntarily stop disposing of their waste at these facilities. An advocacy group for the industry backed the voluntary request and stated its members would comply (Gilliland, 2011), but there are questions about whether self-regulation is working, as the levels of bromide in the source water for Pittsburgh and nearby communities remain high (States *et al.*, 2011; Ferrar *et al.*, 2013). If bromide loading in the basin does not stop, costly changes in water treatment processes will be necessary to avoid violating the US EPA's limits.

The lesson from Pennsylvania is that although the amount of waste, its constituents, and suitability of disposal options will vary, regulatory and political systems must support proactive efforts to understand the potential environmental and human health risks, as well as the concerns of the community. Commercial UGD should not be pursued without a plan for the safe handling and disposal of its wastes, and plans that are enacted must be enforced vigorously. Though Pennsylvania's brief history of disposal of shale gas wastewater has been tumultuous, notable progress has been made with water reuse, drastically reducing the disposal requirements and making the industry much more sustainable, financially and environmentally. When drilling began in 2004, Pennsylvania's regulatory system was ill-prepared for UGD; the growth was overwhelming and numerous regulatory procedures for tracking and enforcing the safe disposal of waste were inadequate.

Pennsylvania is now confronting the issues of handling contaminated solid waste generated from drilling, wastewater treatment and other UGD activities. Proper management of solid wastes requires specialized expertise and an effective regulatory system. A similar pattern of reaction, rather than anticipation, is unfolding.

Distinctive aspects of UGD and its regulation

Production of oil and gas is not new, and many governing bodies already have regulatory systems in place that govern conventional or unconventional oil and gas development. In Texas, for example, UGD is not treated differently from conventional gas development in terms of basic regulatory process. Pennsylvania, however, has recently adopted special regulatory provisions for UGD.

Several factors are unique to the development of unconventional gas resources and require special attention by regulators. The practice of directional drilling (horizontal boreholes) adds additional complexity to designing a permit for a drilling or production unit. Geographic areas allowing access to development activities – typically defined by easements and setbacks – must apply to the surface location, but the subsurface geometry of the producing borehole must also be integrated into the assignment of geographic drilling units. Appropriate information to make these assessments must be required from the operators and reviewed by regulators.

When hydraulic fracturing of a reservoir is employed to stimulate the production of gas, a new level of technical complexity is added that requires specialized regulatory expertise. Because regulators and developers cannot directly observe events occurring thousands of meters below the surface, there is inherent uncertainty about what happens downhole. Although such uncertainty is also present with conventional development, the uncertainty is magnified with UGD due to the complexities of horizontal drilling and the large volumes and chemical composition of materials used during hydraulic fracturing operations. Therefore, the modern process of hydraulic fracturing requires specialized expertise and refined regulatory systems.

An issue of growing concern with respect to all gas development and use, especially UGD, is the potential for loss to the atmosphere of produced natural gas – so-called "fugitive" methane emissions. As explained in Section 2, the climate-control benefits of UGD may not be realized if methane emissions are not controlled. In a recent report, the US EPA found that methane leaks during natural gas production are significant, but lower in magnitude than previously thought (Taylor *et al.*, 2012).

It may be fortunate that shale gas development is proceeding much more slowly in jurisdictions without a strong history of oil and gas development (e.g. North Carolina and Quebec) than in jurisdictions with a strong history (e.g. Alberta, Pennsylvania and Texas). But even in areas with a history of oil and gas production, the rapid rise

in UGD is increasing the concentration of operations, and thereby substantially increasing the potential impacts and visibility of UGD. Consequently, rapid growth in UGD is putting strains on the ability of regulatory bodies to effectively regulate development because of capacity limitations in the public sector, including possible gaps and deficiencies in the design of the regulatory system but also a simple shortage of qualified personnel in the public sector who understand UGD. We therefore turn to the essential ingredients of a regulatory system.

Key components of a regulatory system

This section focuses on components of a regulatory system that are applicable across different systems of property rights, alternative political systems, and different designs of governing bodies. A "comprehensive" regulatory system of UGD is one that addresses each of the key components. In a theoretical sense, the aim of the comprehensive system is to efficiently maximize the overall welfare of society, accounting for both the risks and benefits of UGD (Taylor *et al.*, 2012). Translating the theory into practice, however, is challenging.

Comprehensive systems address five fundamental issues: 1) measurement and documentation of baseline conditions; 2) establishment of technical standards based on best industry practices; 3) implementation mechanisms; 4) oversight of industry compliance through inspections and enforcement; and 5) financial viability of both the regulatory entity and the industry, including adequate mechanisms of financial assurance. At the same time, a comprehensive system should also have the ability to adapt, based on new technical and economic data, and changing public preferences.

Some of the desirable features of regulatory systems seem to be at odds with each other. For example, there is tension between the need for stability and predictability in the conditions that govern a site-specific operating permit (regulatory certainty) and the need for flexibility and adaptability in response to new evidence and unexpected developments. Regulatory systems differ in how much emphasis they give to stability/predictability versus flexibility/adaptability.

Measurement and documentation of baseline conditions

Baseline conditions refer to measuring and documenting the physical and chemical condition of a development site prior to the initiation of development activities. Often these include characterizing the geology, soils, air quality, ecosystems and surface and groundwater systems. This can be accomplished by using existing information, which is often available from government, or by requiring new information to be acquired by developers via testing and analysis. To ensure an effective regulatory approach, baseline assessments should be based on an evaluation of potential pathways for adverse impacts to public health, safety and the environment. Developers should be required to share baseline information with the appropriate regulatory authority.

The baseline measurements required by a regulatory system should be designed based on an evaluation of the potential pathways for contaminants to impact human health, safety and the environment. If those pathways are properly identified, the potential adverse impacts from UGD can be anticipated and prevented or minimized. For example, if the productive reservoir is shallow and relatively close to groundwater supplies, then regulations should focus on mitigating any potential negative impacts to the groundwater system by implementing practices such as establishing minimum distances from wells to buildings and other susceptible areas and/or activities. If the groundwater source cannot be utilized for drinking water due to poor quality, deliverability concerns or prior contamination, regulatory oversight to protect it should be commensurately reduced since the potential public health impact is low. Identified pathways for public health or environmental impacts should be studied, and the baseline monitoring system should address each pathway.

Since reservoirs vary geophysically and geochemically, the resulting plays vary in depth, thickness, composition, distance from groundwater and other subsurface mineral resources, amount and the composition of the formation water and associated hydrocarbons. Evaluating the specific characteristics of the resource will help guide the development of appropriate standards and highlight areas for regulatory priority. Some of the necessary information is available from government while some must be generated by industry. Thus, an effective regulatory system presumes a significant degree of partnership between government and the UGD industry. At the same time, the regulatory agency must have access to the data generated by developers in order to establish detailed regulations tailored to a specific region or area and that are well designed to anticipate and prevent or mitigate possible risks.

For developers, the task of measuring and documenting baseline conditions may seem onerous, especially since the establishment of baseline measurements often requires a partnership (shared responsibility) between government and industry. Recently, one of

the major developers in the US (Chesapeake Energy) offered the EPA the opportunity to conduct before-and-after water sampling tests at one of its drilling sites. The EPA tests are part of a larger study that Congress requested on the environmental impacts of natural gas drilling in the United States.

Adverse impacts to air and water resources can affect communities, economies and individuals. Water and air baseline assessment – including measurements and analyses conducted before shale gas development begins in a new area – provides a metric by which to compare the impact of shale gas development. (American Petroleum Institute guidance (API - HF1) recommends that a baseline assessment program, which includes the sampling of nearby water wells, be conducted prior to hydraulic fracturing operations.) Baseline assessments can include both ambient monitoring over a large area and site-by-site evaluations. Regular measurements for comparison to baseline data are then necessary to assess whether shale gas development has caused cumulative or site-specific adverse impacts. Baseline characterization has most often been used for groundwater and can include assessment of the groundwater quality and quantity, existing pollution levels and sources (urban, industrial or agriculture), and groundwater hydrology such as flow and contaminant transport and biogeochemical interactions and transformations to determine the vulnerability of groundwater to contamination from shale gas development activities.

Baseline assessments may also be useful for spatial planning. Shale gas development is progressing rapidly due in part to the increased flexibility provided by directional drilling and a minimized surface footprint. Although shale gas development is limited to the location of the play, horizontal drilling can reduce some of the surface area impacts and provides increased flexibility to the industry to more fully consider competing land uses and community needs in well siting. Land use planning utilized in coordination with other implementation methods (discussed below) can help locate shale gas operations that enlarge resource extraction in a balance with respect for other community needs. Baseline assessments inform spatial planning efforts that balance the competing demands for natural resource protection and sufficient resources for a variety of industries, economic development efforts, and community needs.

Box 7: Types of monitoring

The following is a listing of the various types and the associated value of monitoring systems. The application of each should be enacted in proportion to the potential risk in a given circumstance.

1. Seismic monitoring – helps detect locations where subsurface injection might provoke seismic activity.

2. Groundwater monitoring – allows for immediate detection of major leakage, but probably not minor leakage. The effectiveness of groundwater monitoring can be heightened by instaling measurement gauges around the well that are linked to a chemical and toxicological monitoring device. Moreover, monitoring measures need to be supported by an emergency plan so that the appropriate response can be initiated quickly.

3. Gas monitoring – allows for assessment of the greenhouse gas footprint based on methane emissions data.

4. Building status monitoring – allows for determination of whether any defects that appear predate a seismic event or were caused by induced seismicity.

5. Leakage monitoring at the well and in pipelines via pressure and other measurements.

Is monitoring meant to be an alarm system or an observation process?

The answer is both. Some processes move faster than others. For example, concerns that polluted deep groundwater has been flowing toward thermal baths for decades can only be validated through long-term monitoring. On the other hand, rapid action is needed for cases in which, for example, contaminants are percolating out of a well or a leaky pipeline. The exact procedures in such cases should be addressed through dialogue with the various concerned parties.

Establishment of technical performance standards

Technical performance standards are drawn from fundamental scientific concepts, analogs and experiences and are grounded, whenever feasible, with baseline information. The standards must be as comprehensive as possible to address the range of potential events that could lead to adverse impacts. The actual standards should be based on baseline assessment, community needs identified in land use plans and on the latest industry best practices. The industry is changing rapidly, and some citizen concerns are being addressed by technological innovation. For example, companies are increasing the use of food-grade chemical additives to replace the BTEX chemicals and in response to restrictions on wastewater disposal, industry is increasingly re-using wastewater, at least in some areas of UGD. The areas where industry innovation and best practices are making the most contributions should be integrated into the assessment process.

Rather than prescribe specific technical practices, some authorities argue that technical standards should be written with performance goals that developers must meet in their compliance plans. Developers should be free to select the most appropriate means of compliance with technical standards. The need for a performance orientation of technical standards was recently emphasized by the UK's Royal Society and Royal Academy of Engineering (Koppelman & Woods, 2012). There are some international standards established through ISO processes as well as industry best practices defined in individual countries or regions (e.g. see the Australian best practice guidelines on development of unconventional gas from coal seams at: http://www.scer.gov.au/workstreams/land-access/coal-seam-gas/). Best practices need to move the entire industry forward but must also be sensitive to cost-benefit and cost-effectiveness concerns.

If pre-drilling activities have appropriately sited well locations, then drilling and production activity regulation can focus on adherence to technical performance standards specific to the jurisdiction. A regulatory system may include technical standards that prescribe minimum well spacing, easements, road use restrictions and procedures for establishing pipeline right-of-ways.

During the production's drilling and development phase, well construction and well integrity standards, water and waste management procedures, and notification/disclosure policies must all be based on technical standards. Standards should include casing and cementing; identification of pathways for fluid migration; management of wastewater; availability of water considering competing uses and environmental impact; and spill and accident response.

Activities that take place during the productive phase of the well's lifetime must also be considered. These include normal operational functions, as well as refracturing and workover operations (major repairs or modifications to increase well production or fix a problem with the well) and need to be addressed with the same technical standards.

Finally, plugging or well closure and site reclamation are critical steps to minimize the long-term impact of shale gas development. A robust regulatory system should have standards to ensure that proper closure (plugging and abandonment procedures) minimizes any risks to other subsurface resources and the surface environment, and that well sites are restored to a level consistent with the surrounding uses.

Since it is predictable that wells will be abandoned, developers should be required to design, construct and operate wells so that they can be suspended or abandoned in a safe manner. Regulators should be notified of abandonment, including periodic reports during the abandonment process.

Technical standards must also address environmental and public health risks, as discussed in Section 2. These risks include:

- Cumulative impacts to essential resources like air and water;
- Effects to landowners near the area of impact;
- Cumulative public health impacts;
- Transportation and infrastructure impacts;
- Impacts on light and noise; and
- Valued features of community character.

Implementation mechanisms

Implementation mechanisms include direct regulation (i.e. prescriptive tools such as operating permits with specified conditions), incentive tools that include liability rules and taxes/subsidies and voluntary practices. The mix of implementation mechanisms depends upon a wide range of technical, political and economic considerations. The goal of implementation is to design a site-specific system that considers and protects regional planning, safety, public health and the environment, corporate interests and landowner and community values.

- Regulatory systems can include a mixture of implementation tools, but most jurisdictions rely primarily on **permits** to meet specific technological standards or to meet environmental or public health goals through performance standards. Permits vary depending on the structure of the regulatory system. For example, if the existing governance framework includes multiple, separate regulatory agencies (one for groundwater, surface water, land use planning), then UGD may be regulated by a multi-permit system. Governing bodies may also choose to consolidate permitting authority into a single permit, thereby increasing regulatory efficiency. Regardless of the underlying regulatory structure, permitting – a multi-step process with potential cross-media impacts – is necessarily complicated and may not fully balance corporate interests, regional planning and community values.

- Often complementary to permitting, **land use planning and monitoring of environmental impact** may also be important implementation mechanisms, particularly if strong baseline assessments are conducted. Environmental impact analysis may already be covered – at least implicitly – in the development of the permit, but in some cases a separate environmental impact process may be appropriate (e.g. at a site where a large number of wells may produce cumulative impacts).

  Land use planning can help identify setbacks for well sites from valued natural or sacred areas, schools and other community features. This planning can also address subsequent property development, community growth, economic development for other industries and natural resource impacts like habitat fragmentation and destruction.

  Land use plans are generally developed at the local level, while permit systems for UGD are typically issued by local offices of state or provincial agencies. Existing land use plans in a community may have been adopted without realization of the opportunity presented by gas development. Most state or provincial regulatory systems do not have a formal mechanism for incorporating local land use considerations into permitting and siting decisions. Since the precise location of the well pad and the orientation of the wellbore are critical to commercial success, existing land use plans may need to be modified to facilitate UGD. Where mineral rights are held by multiple parties, some procedures of unitization and pooling also may be important to facilitate UGD.

- A proper process of **community participation** in permitting and siting projects can facilitate adjustments to UGD that respect important values in existing land use plans. Setbacks for well sites can protect natural or sacred areas, schools and other community features, while accounting for subsequent property development, community growth and economic development of other industries. In some cases, a decision may be made to respect existing land use plans in order to avoid natural resource impacts, such as habitat fragmentation and destruction. When the size of the shale play is large enough to impact several local jurisdictions, community participation in a regional land use planning process may be necessary and appropriate.

- A regulatory system can incorporate additional implementation mechanisms, including industry best practices as performance standards and **incentive-based liability practices**. One of the most recent examples of incentive practices is Pennsylvania's adoption of a "presumptive liability" test for groundwater contamination (similar to the EC Environmental Liability Directive, which is a strict application of the polluter-pay principle). If a drinking water well within 2,500 feet of any well is contaminated, the driller of the well is presumed to have caused the contamination and is liable unless he can show otherwise. This rule puts the onus on the industry and landowners to complete a baseline assessment before drilling starts. The rule balances landowner protection against false claims against the industry, and is not implemented primarily through a permitting mechanism. Insurance requirements may be another mechanism for balancing the industry's needs. Pollution insurance policies, if targeted to the correct risks and to fill gaps in general liability coverage, may be another risk management strategy incorporated into a regulatory system. Financial assurance requirements, including bonds or trusts, are commonly used to cover activities in which the regulatory incentives are not effective. In most cases, incentive-based mechanisms are supplements rather than alternatives to direct regulation.

Oversight of compliance

A robust system of inspections, enforcement and punishment is essential to an effective regulatory system. When done correctly and communicated appropriately, the enforcement process provides information to the industry and the public about the types and frequencies of violations that may have public health, safety and environmental impacts. Therefore, this process acts as a reassurance that the industry is collectively abiding by the protective technical standards. Since penalties are assigned to specific violators rather than the whole industry, non-offending developers do not necessarily suffer damage to their reputations from an enforcement action. Data on violations can also be analyzed for trends and clustering in specific regions. All of these virtues of a robust system make some key assumptions:

adequate resources, expertise and manpower are made available for inspections, enforcement and prosecution of violators; there is a political will to enforce the conditions of permits; and the process focuses on protecting human health, ensuring safety and minimizing environmental impact.

Regarding the inspection process, the frequency and timing of inspections must be sufficient from a deterrence perspective to influence developer behavior in all phases of UGD over a sustained period of time. The Texas Railroad Commission, for example, sponsors about 120,000 inspections per year, but still relies in part on community complaints to identify problematic operations. There are high-priority areas for inspections (e.g. well casing operations), but others need to be determined as data are accumulated over time. Oversight during this time is critical to ensure the cementing of the well casing meets the technical standards.

Penalties for violations must be set to serve as an effective deterrent, but they may also play a role in boosting public trust in the system and providing funding for the agencies to conduct essential investigative operations.

Making enforcement information publicly available allows independent analysts to search for patterns in the data, identify possible cumulative impacts, and highlight areas in the process where innovative and more protective standards may be necessary. In cases where an enforcement system is not considered credible, it may be necessary to implement independent audits to ensure durability.

Financial viability

A regulatory system must be financially sustainable, which includes consideration of financial burdens on the industry, the regulatory agency and the public at large.

Regulatory agency funding must be sufficient to provide:

- Staff and technology for permit review;
- Outreach and coordination with the public and industry;
- Enforcement and inspections;
- Staff training; and
- Data collection and management.

Funding should also be adequate to address impacts from all stages of shale development. Regulatory agencies can be funded through permit fees paid directly to the agency, severance taxes on produced gas, royalties on public lands, general funds or through direct appropriations.

A regulatory system should also consider the life cycle of the specific development by the industry when creating financial mechanisms. Environmental issues requiring remediation may occur at any stage. To reduce the risk of unfunded environmental externalities, regulatory systems generally require **financial assurance from the industry**, often in the form of a surety or bond to the regulatory agency. Financial assurance requirements may only be effective if they are commensurate with the environmental costs to be internalized. For activities such as well plugging and abandonment, financial assurance requirements incentivize the operator to perform the reclamation. In general, failure to perform activities subject to financial assurance results in the bonded or otherwise held monies going to the regulatory agency to perform the work. Financial assurance requirements can be comprehensive – applying to proper well closure, restoring the surface to pre-development conditions, and remediation of contamination caused by the drilling operation. Costs of reclamation projects can vary widely and a current challenge is providing sufficient incentive for operators to perform activities required by regulation. Financial assurance requirements may apply to single operators or wells and often allow for multiple wells of a single operator covered by a blanket bond (GAO, 2010). Some bonding requirements can be increased or decreased based on factors identified by the regulatory agency, such as well depth or number of wells on a well pad.

Other financial assurance mechanisms for addressing the clean-up associated with these events include payment into trust funds managed by the state or federal government and insurance requirements. Experience with these mechanisms for other industrial sectors has not been wholly positive. The trust funds are often outpaced by the costs of the clean-up or the numbers of abandoned sites. Bonding and insurance may be insufficient for the level of environmental or public impact. Outreach and work with the industry, insurers and the public may lead to a financially viable approach.

Complications arise when the company responsible for production subcontracts with other companies to handle closure and post-closure issues. Regulators may need to examine the subcontracts to ensure that proper expertise and economic resources are available to follow through on reclamation of a site and post-closure monitoring. Without clear financial arrangements, unexpected costs that arise in the post-closure setting may be a target of

avoidance by all firms associated with a particular play. Financial viability also includes the industry's economic needs – a stringent regulatory system with large fees may fail to account for the financial viability of the industry and thus serve as a de facto prohibition on UGD. Most states assess a **severance tax** that is calculated based on the gross value of the shale gas. States vary, however, in calculating "value," which may be reduced by production costs, ad valorem taxes or royalties paid to mineral rights owners. Fees and assessments may also affect the financial viability of shale gas development. Other related fees include corporate income taxes, real property taxes, personal property taxes, sales and use taxes, impact fees and permit fees (which are discussed above). A fee assessed to offset an identified community impact such as degrading transportation infrastructure or increased emergency responder costs is another option.

When the overall costs of the regulatory system on industry are considered (e.g. the costs of obtaining permits, meeting technical standards, paying royalties and fees), a determination must be made that each cost is necessary, balanced by the fiscal incentives available, and that the overall burden is not excessive in the context of an evolving industry. A policy judgment is required to achieve the best balance of economic gains for industry, communities and consumers and risks to communities, public health and the environment. Such policy judgments can be expected to vary across political systems.

Box 8: Shale gas regulations in the US

The Center for Energy Economics and Policy at Resources for the Future is analyzing regulations in the 31 states in the continental United States that have significant shale gas reserves or where industry has shown interest in shale gas development. It publishes maps to show which important regulatory elements are included, and how, in each state.

The purpose of these maps is to provide an overview of the regulatory patterns, similarities and differences among states – not to authoritatively compile any given state's regulations or fully analyze any specific regulation. The maps show state-level regulation (local regulation is excluded) and states that regulate via the permitting process.

In US states, regulation covers or can cover the following elements:

Site development and preparation:

- Pre-drilling water well testing
- Water withdrawals
- Setback restrictions from residential and other buildings
- Setback restrictions from municipal and other water sources

Well drilling and production:

- Cement type regulation
- Casing and cementing depth
- Surface casing cement circulation regulations
- Intermediate casing cement circulation regulations
- Production casing cement circulation regulations
- Venting regulation
- Flaring regulation
- Fracking fluid disclosure

For more information and for updates: http://www.rff.org/centers/energy_economics_and_policy/Pages/Shale_Maps.aspx

Flowback/wastewater storage and disposal:

- Fluid storage options
- Freeboard requirements
- Pit liner requirements
- Flowback/wastewater transportation tracking
- Underground injection wells for flowback/wastewater and produced water

Well plugging and abandonment:

- Well idle time
- Temporary abandonment

Well inspection and enforcement:

- Accident reporting requirements
- Number of wells per inspector
- Number of regulating state agencies

Other:

- State and local bans and moratoria
- Severance tax calculation methods
- Severance tax rates

Stakeholder coordination, education and participation in the regulatory system

Proper stakeholder engagement in the regulatory process builds trust between parties with diverse viewpoints, ensures all views are considered and balanced in the regulatory system, and creates a check on the integrity of the regulatory system. Stakeholders include the shale gas development industry, representatives of state and local governments, environmental advocacy interests, landowners and the public. In North America stakeholders may also include First Nations with inherent rights in a particular geographic area. Overly limited stakeholder coordination, education and participation can lead to dysfunctional controversy, thereby slowing the development of a particular site or region.

Stakeholder concerns are not necessarily the top concerns of scientists and engineers. Whether the issue is excessive flaring, noise levels, traffic concerns or fears of excess water use, the regulatory system must be flexible enough to respond to stakeholder concerns. Where similar concerns have been raised by stakeholders at multiple sites, it is wise for industry and regulators to act proactively to address such concerns rather than be put on the defensive by reacting only after complaints are lodged. In British Columbia (Canada), for example, the Oil and Gas Commission has found it advisable to develop proactive policies on the specific subject of flaring.

Stakeholder participation occurs at multiple levels. It should be incorporated into the process for determining the appropriate regulatory system and, after the regulatory system is established, in site-specific permit decisions. Stakeholders should have input into how a regulatory system is constructed, including specific regulations, technical standards, assigning governing authority, and the use of permits or other implementation mechanisms. A good illustration of stakeholder engagement in the design of a regulatory framework is the framework for coal seam gas led by the government of Australia (Australia, 2012).

Full participation by any stakeholder is directly associated with the degree to which stakeholders have a common understanding and familiarity with UG exploration and production. As illustrated by the large public acceptance of UGD in Poland, understanding and familiarity can increase community acceptance, industry accountability and investment in the area, and contextualizes regulatory decisions. Poor understanding of the details involved in UGD presents a challenge for both the industry to operate and the development of an effective regulatory system. Such a lack of understanding often reduces tolerance of risks and accidents, leading to violations of the “social license to operate.” Increased education, interaction among stakeholders, and recognition and response to divergent values may create a regulatory system that more closely balances the development of shale resources with potentially competing uses and values.

Box 9: The trend toward public disclosure of hydraulic fracturing fluids

Stakeholder engagement exercises can lead to frustration and mistrust when participants have unequal access to technical information. Controversy about UGD has erupted in some jurisdictions because detailed information on the hydraulic fracturing fluids used by service companies is not typically made available to the public. The issue represents a tradeoff between the commercial interest in protecting confidential business information (trade secrets) and the public interest in access to information relevant to safety determinations.

Fluids used for hydraulic fracturing, while predominantly comprised of water and sand, contain a wide variety of chemicals such as acids, biocides, corrosion inhibitors, friction reducers, gelling agents and oxygen scavengers. Each chemical is included in the fluid for a particular purpose, and companies compete with each other based on innovation in the mix of chemicals that are used. Not surprisingly, there is concern among communities and health professionals about the constituents and their potential health effects. Adequate toxicity data do not exist for some of the chemicals currently in use, and there is uncertainty about appropriate medical responses to human exposure when spills or leaks of hydraulic fracturing fluids occur.

The trend in North America is toward more public disclosure of information about hydraulic fracturing fluids, although claims of confidential business information have not been wholly ignored. A group of state regulators has formed a chemical disclosure registry called FracFocus (www.fracfocus.org), in which 200 companies have registered information about the chemicals used at more than 15,000 sites in the United States. Several states have gone further, compelling energy companies to disclose more information than is currently available on FracFocus.

In February 2012 the Texas Railroad Commission implemented the "Hydraulic Fracturing Disclosure Rule," one of the most comprehensive rules for public disclosure of chemical ingredients used in hydraulic fracturing fluids. The rule compels developers to disclose the type and amount of chemicals used (including water volumes) on the FracFocus website. The rule was partly a response to public concern that chemicals in hydraulic fracturing fluid were highly toxic and potentially detrimental to human health and safety.

For Europe, the International Association of Oil and Gas Producers (OGP) launched in 2013 a platform for voluntary disclosure of chemical additives on a well-by-well basis in the European Economic Area (EEA) at: http://www.ngsfacts.org/

In conclusion, transparency of the entire regulatory system is generally critical to effective community participation and stakeholder engagement. Without transparency, a regulatory system will become vulnerable to various forms of corruption, incompetence and disregard for community norms.

Box 10: Recognizing and complying with existing EU environmental law will be crucial for UCD in Europe

As of this report's writing, the European Commission is considering whether or not it needs to regulate the exploration and exploitation of unconventional oil and gas. The effort is led by the Directorate General for the Environment, with participation from DG Climate and Energy. As indicated in Section 3, DG Environment is preparing a risk management framework to deal with technical issues, which is expected to be released at the end of 2013. A recent workshop held in March, 2013 explored these issues (Eriksson *et al.*, 2013).

According to the consultation mentioned in Section 3 a majority of the EC population believes that the EC should clarify the existing EU legislation through guidelines, and an even larger majority believes that it should develop a comprehensive and specific EU piece of legislation for unconventional fossil fuels. A minority believes that adapting individual pieces of existing EU legislation would be enough. Such a regulation or any other ways to ensure safe, secure and sustainable operations is expected to focus in particular on the need to acquire, collect and share information for:

- Transparency of operations (operators, their licenses and permits for planned developments);
- Collection of baseline data prior to commencement of operations (e.g. on volumes or water used and chemical additives);
- Information on potential risks related to exploration and production;
- Information on potential benefits; and
- Information on incidents.

EU environmental regulation, particularly for the protection of water quality, is very comprehensive. According to some, existing regulations in Europe are sufficient to prevent UGD risks (primarily exploitation and production) from causing harm to people's health and the environment, both in the short term and in the long term. According to others, there are gaps which need to be filled, lack of consistency, and need for a specific regulation.

Existing regulations include:

The Water Framework Directive (WFD – 2000/60/EC) requires all EU waters, including groundwater, to achieve "good status" by 2015, which includes both ecological and chemical status, and more specifically "the least possible changes to good groundwater status, given impacts that could not reasonably have been avoided due to the nature of the human activity or pollution."

The Groundwater Directive (2006/118/EC) aims to prevent or limit pollutants to groundwater. Hydraulic fracturing with concrete casings can be carried out without damaging groundwater supplies, but the industry will have to meet mandatory environmental tests.

The Drinking Water Directive (98/83/EC) includes strict, wide-ranging parameters for levels of chemicals in drinking water.

The Priority Substances Directive (2008/105/EC) focuses extra controls on some 33 initial priority hazardous substances in an attempt to ensure these do not enter EU-controlled water supplies.

The REACH Chemicals Regulation (1907/2006) controls most chemical substances placed in the EU market and applies particularly strict controls to Substances of Very High Concern – notably: carcinogens, mutagens, reprotoxins, persistent bioaccumulative and toxic substances; very persistent and very bioaccumulative substances; and substances of equivalent concern such as endocrine disrupters. This legislation will have important indirect effects on chemical usage in fracturing fluids used for unconventional gas production. Full disclosure of chemicals used will be required under this full directive.

The Waste Framework Directive (2006/12/EC) applies to the disposal of large volumes of flowback water if it is "contaminated" by chemical substances.

The Environmental Impact Assessment Directive (2011/92/EU) makes baseline assessment compulsory above a certain threshold. Some argue that Strategic Environmental Assessments (SEAs) should be made compulsory in all UG projects. One positive effect might be to reassure the population that long-term negative impacts would be avoided or minimized.

The Environmental Liability Directive (2004/35/EC) will require operators to clean up and restore the environment following exploration and production operations, over and above any national programs relevant to land contaminated by unconventional gas activities. This directive applies above a certain threshold determined by the size of the project.

The Seveso III Directive (2012/18/EU) prevents industrial accidents.

As indicated in Section 3, DG Environment is preparing a risk management framework to deal with technical issues, which is expected to be released at the end of 2013. According to the European Commission website[7], the initiative consists of an "'Environmental, Climate and Energy Assessment Framework to Enable Safe and Secure Unconventional Hydrocarbon Extraction' … (subject to an Impact Assessment). This initiative will aim at delivering a framework to manage risks, address regulatory shortcomings, and provide maximum legal clarity and predictability to both market operators and citizens across the EU. An Impact Assessment will look at options to prevent, reduce and manage surface and subsurface risks, to adapt monitoring, reporting and transparency requirements, and to clarify the EU regulatory framework with regard to both exploration and extraction activities."

A related question that the EC will have to address is the level of governance: should technical and administrative matters and measures be dealt with at the European, national or regional level?

Another area of debate in Europe is whether voluntary measures (yet to be developed, mainly by the industry) would be sufficient, including for providing public confidence, or whether binding/mandatory measures are needed. European citizens may expect strict regulation. The European oil and gas industry is heavily regulated and might prefer to develop its own voluntary standards.

[7] http://ec.europa.eu/environment/integration/energy/unconventional_en.htm

Recommendations

1. Understand and evaluate the general regulatory environment to ensure that shale development regulation is consistent with existing regulatory systems. If it diverges, provide an explanation to support the difference.

    a. Review the existing regulatory system, identify the current role of public and private entities. Understand the geology and shale gas resource and identify other jurisdictions with similar geology as a source of analogous technical standards. Identify regulatory gaps.

    b. Assign regulatory authority: assess current division of authority; share responsibility for managing risks between government and industry; create mechanisms that improve coordination of governmental divisions, industry and stakeholders; since public expectations and trust in government and industry varies, assign authority and responsibility consistent with public expectations.

2. Regulatory systems have five key components: baseline assessments; technical standards; implementation mechanisms; enforcement and oversight; and financial viability.

    a. Conduct a baseline assessment of the source rock, impact pathways for water or air contamination, community values or expectations (rural versus urban environment) and conduct land use planning as appropriate for the jurisdiction.

    b. Technical standards must address all steps in the process: exploration through plugging and abandonment; cover all environmental and public health risks; and be tailored to the source rock and community values.

    c. Implementation mechanisms should include prescriptive permitting, incentives and voluntary practices as appropriate for the jurisdiction.

    d. Enforcement and oversight should have provisions for adequate level and frequency of inspections, data management and analysis, and sufficient fines and penalties.

    e. Financial viability entails making sure that the regulatory entity is properly funded, that the technical standards are affordable for industry, and that financial assurance mechanisms are available to address spills, accidents and abandoned sites.

3. Stakeholder engagement, education and participation are the bedrock for a legitimate regulatory system, and transparency of the regulatory system is a prerequisite to effective stakeholder engagement.

    a. Stakeholders should be involved in establishing the regulatory system and the regulatory system should include provisions for involving affected communities and other stakeholders. Education for all stakeholders builds relationships, fosters understanding for diverse viewpoints, and may result in innovative solutions.

    b. Stakeholder and community trust in UGD operations would be enhanced if energy companies were required to disclose publicly more information about the chemicals that are used as drilling fluids, though some degree of non-disclosure may be necessary to protect confidential business information.

Section 5:

Roundtable on responsible UGD

Based on the findings of this evaluation, there is an urgent need for the establishment of a "roundtable" where technical, economic, regulatory and political developments related to unconventional gas development can be discussed among stakeholders from different regions of the globe on a regular basis. The rationale for such a forum has been echoed in conversations with dozens of practitioners in public and private organizations in both the developing and developed world.

As there is significant variability in UGD projects around the world, much can be learned as practitioners share site-specific experiences with others in the field. The same concerns about UGD are being raised repeatedly at different locations, and lessons about how these concerns are addressed should be shared as widely as possible. More broadly, political jurisdictions vary in how energy policies are modified to promote or accommodate UGD, and how pursuit of UGD is being coordinated with policies to slow the pace of global climate change. It is very likely that the roundtable could also facilitate learning on these broader issues.

Given how rapidly the unconventional gas industry is growing and how many new projects are likely to be launched in the next decade or two, now is the critical time for stakeholders to form a global roundtable that would facilitate shared learning. Moreover, the roundtable would serve as a venue where various stakeholders can discuss the evolution of technical and regulatory systems, how well the systems are working, and how further modernization of technical and regulatory systems could serve the interests of diverse stakeholders and the public. Currently, formal technical expertise and informal knowledge about the UGD industry are concentrated among professionals in a limited number of companies, making it difficult for regulators, investors, academics, NGOs and other stakeholders to access reliable information and engage directly with corporate experts on open and equal grounds.

To some extent, the needs for information sharing are met by a variety of bilateral communications (e.g. the exchanges of information about UGD between the US and China and between Canada and India). Although bilateral dialogue is encouraged, it does not bring other governments to the table, and it is not always accessible to stakeholders in nations outside of these arrangements. There have been proposals to create some roundtables or platforms on a regional basis. For example, a workshop organized in March 2013 by the European Commission's Joint Research Centre Institute for Energy and Transport led to the conclusion that creating a European platform on UGD would be beneficial in Europe. The IRGC supports such regional platforms, but believes they cannot accomplish the same objectives as a global roundtable.

The development of the unconventional gas industry has global ramifications. Many professionals we interviewed believe that UGD is already altering the balance of power among nations and regions of the globe, restructuring global energy markets, tapping scarce water resources, changing national energy policies and influencing strategies to address global climate change. Given that unconventional gas resources are distributed throughout the globe and that resource development has global ramifications, a global roundtable organized around a few key functions can make a constructive contribution that bilateral or regional exercises cannot fulfill.

Useful reports on UGD have been produced by a variety of consulting firms, think tanks, universities and international organizations. While these reports (which are listed and annotated in the Appendix) have produced significant insights, none of the sponsoring organizations for the reports have stepped forward and proposed to sponsor the kind of regular global roundtable that we believe would be of significant value. The complexities of a global forum are admittedly daunting, especially since financial support must be secured from multiple sources (e.g. governments, international agencies, corporations and foundations) and a governing structure and philosophy for the roundtable would need to be established.

In light of the complexities, the IRGC has taken the additional steps of suggesting what a global roundtable on UGD could look like, what its mission could be, how it could be organized, and proposed funding models. We conclude this report by proposing specific functions for the roundtable to give the concept some practical clarity.

Organization

A private, non-profit independent body, or consortium, of concerned stakeholders should be formed to establish a forum for regular dialogue about unconventional gas development issues. It could be an entirely new organization, or it could be housed within an existing organization. Stakeholders with a wide range of

views about UGD would be invited to participate with the request to provide evidence-based knowledge for improving practices, policies and understanding of UGD, and sharing that knowledge gained in one part of the world with others.

A multi-stakeholder membership organization

To represent the various facets of development and their stakeholders, the roundtable should be comprised of representatives from at least six stakeholder groups:

- Business and industry: oil and gas exploration and production companies, service providers and suppliers, investment firms and insurers;
- National and regional scientific organizations: geological and engineering trade associations, risk analysts and communicators;
- Policymakers and analysts: international organizations, elected officials and their staff, energy and environmental ministries, and advisors/consultants in science and technology;
- Regulators: federal, national, state/provincial and local/municipal regulators;
- Civic society: local community leaders, environmental and consumer NGOs, public health groups; and
- Colleges and universities: faculty and students with research and educational activities related to UGD.

Depending on how the roundtable evolves, it may be useful to establish chapters where stakeholders in a particular group meet separately (perhaps via webcast) to generate priority issues for discussion and propose participants to represent the chapter in the regular global forum. In this way, the agenda and participants for the global roundtable would be generated in a grassroots manner rather than defined only by a small group of conference organizers.

Recommended primary roles of each chapter:

- Industry: to explore the safety culture in the industry, thereby paving the way for sustainable unconventional gas development and the benefits it provides in affordability, reliability and environmental protection;
- Science: to provide and help others interpret data and information and identify research needs and priorities;
- Policymakers: to access trusted information and share views about policy goals and legislative issues;
- Regulators: to discuss the development and improvement of regulatory frameworks consistent with political decisions about health, safety and environmental protection; affordable energy; energy security; and overall economic, environmental and social sustainability;
- Civic society (local communities, consumer groups, and environmental NGOs): to primarily enhance dialogue for better decision-making and
- Colleges and universities: to discuss educational priorities related to UGD as well as scientific collaboration.

International scope

As Canada and the United States have accumulated most of the experience with UGD to date, North American participation is crucial. Europe is currently divided on the future of UGD but significant interest is apparent in the United Kingdom, Poland and some other EU member states. The European Commission is also devoting more priority attention to this issue. In China and India, UGD is already viewed as a crucial energy issue and many countries in the developing world are beginning to establish policies and regulatory systems for UGD. Even countries lacking unconventional gas reserves (or that have no commercial interest in UGD) may have interests in learning about the future of UGD, since it may affect their energy systems or offer insights into whether they can rely on UGD for importation of natural gas. To ensure efficient use of resources, the global roundtable must complement other initiatives while avoiding unproductive overlap.

Venue

The roundtable should have an independent host that is globally accessible. Meetings and venues should be chosen to further the mission of the roundtable, and should continue at regular intervals as the exploration of UGD and the technology continues to evolve. The platform should also have a distributed and comprehensive digital component. Networking capacities should be maximized to create continuous engagement in the primary functions of the roundtable, whether hosting panel discussions, sponsoring webinars, or offering continuing education classes.

Box 11: Examples of constructive roundtable discussions

- In 2012, the International Energy Agency announced the formation of a platform described as follows: "At their recent Camp David summit, G8 leaders welcomed and agreed to review this IEA work on potential best practices for natural gas development. 'To build on the Golden Rules, we are establishing a high-level platform so that governments can share insights on the policy and regulatory action that can accompany an expansion in unconventional gas production, shale gas in particular,' said Maria van der Hoeven. 'This platform will be open to IEA members and non-members alike.'"
  http://www.iea.org/newsroomandevents/pressreleases/2012/may/name,27266,en.html

- The Center for Sustainable Shale Development (CSSD), a collaboration built on engagement among environmental organizations, philanthropic foundations and several energy companies from across the Appalachian Basin, aims to develop rigorous performance standards for sustainable shale development and commit to continuous improvement to ensure safe and environmentally responsible development of the resources. CSSD strives to offer an independent, third-party evaluation process to certify companies that achieve and maintain these standards.
  http://www.sustainableshale.org/

- The Roundtable on Sustainable Biofuels (RSB) is an international multi-stakeholder initiative that brings together farmers, companies, NGOs, experts, governments and inter-governmental agencies concerned with ensuring the sustainability of biofuels production and processing. Participation in the RSB is open to any organization working in a field relevant to biofuels sustainability. This platform was launched in 2007 by three core funders: EPFL (Ecole Polytechnique Fédérale de Lausanne, Switzerland), Shell and the National Wildlife Federation.
  http://rsb.org/

Objective

The primary mission of the roundtable should be information sharing on technical, economic, regulatory and political issues related to UGD. Through information sharing, the roundtable could contribute to the wise implementation of appropriate restrictions on development as well as practices that assure the safe, efficient, sustainable and responsible development of unconventional gas resources. Once the roundtable is firmly established, it may expand its mission to include consensus building with regard to best practices in UGD – whether those practices are technical in nature or relate to how community participation in UGD should be organized. Since many organizations already exist to advocate for and against UGD, the case for transforming the roundtable into an advocacy organization is not strong.

Functions

The roundtable may consider the following areas where information sharing among stakeholders would be beneficial to develop unconventional gas in a safe, sustainable and responsible manner.

Dissemination of reliable information and promotion of knowledge transfer

The technologies and processes involved in UGD continue to change at a rapid pace. Information on these technologies and processes and the risks associated with their use can be difficult to access and understand. Creating a publicly accessible system for organizing data collection and experience sharing, and for submission and publication of reliable information in multiple languages, is a desirable function of the roundtable. If the roundtable accepts the role of global clearinghouse for information related to UGD, it must be impartial and accepting of alternative views, but should not host widely discredited information.

Beyond passive sharing of information, the IRGC believes an important function of the roundtable could be to promote knowledge transfer. This may involve sharing of experiences but may also include formal certification or education programs. Mechanisms for transferring knowledge are well established in the oil and gas industry; it occurs when companies are hired and acquired, and it is also supported by existing industry organizations. The roundtable can fill a critical void by also being a forum for regulators, researchers, citizens and other stakeholders to share their tacit and explicit knowledge and engage with interested parties across the globe.

Box 12: Industry associations involved in data and experience collection and sharing

Technical guidelines and recommendations of best practice are also produced by these associations:

- The Canadian Association of Petroleum Producers (CAPP) has designed with its members a set of Guiding Principles and Operating Practices for Hydraulic Fracturing.
  http://www.capp.ca/canadaIndustry/naturalGas/ShaleGas/Pages/default.aspx#operating

- The Canadian Society for Unconventional Resources is a not-for-profit society active in promoting responsible development of unconventional hydrocarbon resources in Canada.
  http://www.csur.com/

- The American Petroleum Industry (APPI) is working with its members to develop guidelines for safe and efficient shale gas operations.

- The International Association of Oil and Gas Producers (OGP) is collecting sets of best practices, notably to demonstrate the importance of pilot and demonstration projects with involvement of independent research institutions.
  http://www.ogp.org.uk/global-insight/gas-from-shale/

- The German Industrial Association for Mineral Oil and Natural Gas Extraction (WEG) is developing standards and guidelines for natural gas development.
  http://www.erdoel-erdgas.de/Themen/Technik-Standards

Box 13: Knowledge transfer on technical, regulatory and policy issues between nations

As per the Organisation for Economic Co-operation and Development (OECD) principles for technical and financial assistance (OECD, 2003), technical cooperation between nations can increase the institutional capability of organizations to fulfill their roles and responsibilities with respect to the safety of hazardous installations. Such technical cooperation and experience sharing can address, for example, assistance related to implementation of risk assessment and risk management programs, including accident prevention, emergency planning and accident response.

Programs for capacity building and experience sharing need to:

- Be responsive to specific, well-defined needs (i.e. be “demand driven”) and be results oriented;
- Utilize local experts and local languages;
- Take into account a long-term perspective; and
- Include active participation of all relevant stakeholders (e.g. public authorities, industry, including labor, and community organizations).

Capacity building for community and stakeholder participation

Political and societal legitimacy involves earning the trust of local communities, elected officials and other stakeholders. To the industry, political and social legitimacy is its license to operate. UG operations may be obstructed by the public or be subject to undue regulatory/political interference when the level of trust is low.

Many promising technologies, from nuclear energy to genetic engineering, have been hampered in their commercialization because the concerns of stakeholders and the public are not addressed effectively. When innovators are not aware of the need to involve the stakeholders, or are not trained or experienced in stakeholder engagement, they may not accomplish an appropriate type or degree of community participation. Even when industrial companies make responsible, science-based efforts at stakeholder engagement (see Box 4: Dialogue process on UGD in Germany), it does not guarantee that communities will accept – promptly or eventually – a new technology that creates potential risks for human health, safety and/or the environment.

The concerns about UGD that motivate academics and national environmental leaders are not necessarily the same concerns that activate grassroots community residents who live near UG wells. Journalists find that community residents are most vocal about annoyances such as noise, smell, traffic congestion and potential adverse impact on resale values of properties. One of the most frequent complaints is about truck traffic. Drilling and fracking a single well can require 1,000 or more truck trips, as the vehicles haul equipment, workers, sand, drilling fluids and wastewater (Gold & McGinty, 2013). Addressing the concerns of community residents may be different than addressing the concerns of scientists and professional environmentalists.

Nor should it be assumed that community acceptance challenges will be confined to towns near wellheads. A vibrant UG industry must have infrastructure to support the drilling activity. The growth of production of sand used as a proppant in hydraulic fracturing, a crucial component of the UG industry in the US, is located in states (e.g. Wisconsin and Minnesota) that do not have gas production (Marley & Bergquist, 2013). Yet sand mining, if not managed properly, raises community concerns. The air emissions from gas-processing facilities have triggered community concerns. Pipelines are increasingly needed to bring gas to markets and freshwater from rivers to drilling sites but some communities are objecting to the large withdrawals from rivers or to the construction of pipelines (Gold, 2013b). And the sites for disposal of wastewater may be located in different towns (or even different states/provinces) to the drilling sites. Some town officials in the State of Ohio are objecting to the disposal of drilling wastes that are transported from wells in Pennsylvania (Downing, 2013; Bell, 2013b). Thus, there is a pressing need for international and regional sharing of information on how to address community concerns about the entire life cyle of UGD.

Political and social systems vary, but the roundtable can help government, industry and other stakeholders share community engagement experiences as they unfold around the world. With a forum for exchanging information about these experiences, IRGC expects that community engagement activities will continue to evolve and improve.

Strengthening safety cultures

Complex industrial procedures require sophisticated processes to enhance the safety of industrial operations and individual behaviors. These procedures benefit from being developed with others. Improvements in safety management practices have resulted in highly developed “cultures of safety” that address the specific concerns of individual companies and promote the integration of companies into the social fabric of the communities in which they operate (OECD, 2003). The main characteristic of a “culture of safety” (KAS, 2008; Baker *et al.*, 2007) is viewed in the way managers and staff focus their attention on accomplishing safety through close mutual cooperation.

For example, operational safety can be organized proactively by the following measures (and others):

- Establishment and integration of a safety management system into company operations;
- Providing employees with safety training;
- Ensuring that external company personnel apply equally exacting safety standards;
- Setting aside sufficient time and financial resources for safety;
- Defining safety performance indicators (API, 2010; CCPS, 2011; CEFIC, 2011);
- Learning lessons from operational experience and accidents;
- Achieving preparedness if accidents and emergencies occur;
- Conducting regular audits and management reviews of installation safety and performance.

Although work is required to tailor these general measures to the specific case of UGD, a key function of the roundtable would be to foster a culture of safety around UGD that is ultimately reflected in the day-to-day practices of industry, regulators and other decision-makers.

Clarifying how UGD can serve as a bridge to a low-carbon, sustainable energy future

One of the promises of UGD is to facilitate the transition of economies to a lower-carbon future that is environmentally sustainable, socially acceptable and economically viable.

Natural gas is the cleanest burning fossil fuel, but emissions associated with UGD and delivery of natural gas to consumers may offset some of the gains. Mitigating and, where possible, avoiding the impacts of climate change is a global imperative and an important part of the context in which the unconventional gas industry operates. Proponents of UGD tout the potential for natural gas to serve as a transition or "bridge" fuel to a lower-carbon future. For this to become reality, technology lock-ins that would block the transition to more sustainable energy sources must be avoided. The unconventional gas industry, its regulators, the public and other stakeholders must play an active role in overseeing this transition. The roundtable should provide a forum for stakeholders to address failings, promote achievements and to debate critical climate-related issues such as recoverable resources and methane emissions. The roundtable may also promote more efficient uses and ways to conserve natural gas, and advocate for policy changes that can achieve these objectives.

Conclusions

At the IRGC November 2012 workshop and in ensuing conversations, the IRGC has learned of several promising organizations and partnerships supporting responsible UGD, as well as positive impacts from grassroots efforts and corporate outreach. The IRGC is also familiar with the environmental and human health risks of UGD, and has witnessed strong opposition to UGD from some governments, citizens and other stakeholders. UGD's global potential is undermined if risks to land, water and air are not properly understood, managed and communicated when UGD is undertaken. On a global scale, the IRGC believes there is an urgent need to share information and transfer knowledge, build capacities for community and stakeholder engagement, address climate change issues and strengthen safety cultures. A global roundtable with a cross section of relevant stakeholders should be organized to advance these objectives.

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Appendix:
Tabulation of enhanced natural gas production resources

Section summaries

The reference guide is split into six sections containing various technical reports, papers and summaries on enhanced natural gas production. A common thread is that they examine the consequences of increased shale gas production through hydraulic fracturing techniques on areas pertaining to the economics of natural gas, public perceptions of natural gas and a host of infrastructure related subtopics. The first category of reports explores the impact of enhanced natural gas production on greenhouse gas emissions; this is then followed by a section comprised of articles that address the potential air, water and land impacts associated with the increased production of natural gas and, particularly, shale gas. The third group of references examines the impacts of enhanced natural gas liquefaction and its potential effects on maritime trade. The subsequent section documents technical papers that delve into the role that enhanced natural gas production will have on the electric generation and transportation sectors. Section five contains reports that investigate potential distribution restrictions associated with accessing this increased supply of natural gas, which has primarily been bolstered through various shale discoveries across the United States. Examples of distribution restrictions include, but are not limited to: access to pipeline infrastructure, the viability of access to processing facilities and the ability to access storage systems (depleted oil or gas wells, underground aquifers or salt caverns). The final section of resources deals with studies that examine stakeholder engagement in the natural gas industry, public perceptions of enhanced production and the current system of regulatory oversight that governs resource extraction.

Greenhouse gas emissions

Lev-On, M. & Shires, T., 2012, *Characterizing Pivotal Sources of Methane Emissions from Natural Gas Production*, American Petroleum Institute and America's Natural Gas Alliance. Available at: http://www.api.org/~/media/Files/News/2012/12-October/API-ANGA-Survey-Report.pdf

Overview

This study presents the updated results from a collaborative effort among members of the American Petroleum Institute (API) and America's Natural Gas Alliance (ANGA) to gather data on key natural gas production activities and equipment emission sources that are essential to developing estimates of methane emissions from upstream natural gas production. In an attempt to provide additional data and identify uncertainty in existing datasets, the API and ANGA conducted this joint study on methane (CH_4) emissions from natural gas production operations starting in July 2011. API/ANGA collected data on 91,000 wells distributed over a broad geographic area and operated by over 20 companies; this represents nearly one fifth of the estimated number of total wells used in EPA's 2010 emissions inventory. Ultimately, this project was directed toward gathering more robust information on workovers, completions, liquids unloading, centrifugal compressors and pneumatic controllers with the intent of supporting revisions to the activity factors used in EPA's national inventory.

Fulton, M., Mellquist, N., Kitasei, S. & Bluestein, J., 2011, *Comparing Life-Cycle Greenhouse Gas Emissions from Natural Gas and Coal*, Worldwatch Institute. Available at: http://www.worldwatch.org/system/files/pdf/Natural_Gas_LCA_Update_082511.pdf

Overview

Natural gas has been widely discussed as a less carbon-intensive alternative to coal as a power sector fuel. In April 2011, the US EPA released revised methodologies for estimating fugitive methane emissions from natural gas systems. These revisions mostly affected the production component of the natural gas value chain, causing a very substantial increase in the methane emissions estimate from US natural gas systems. This large increase in the upstream component of the natural gas value chain caused some to question the GHG advantage of gas versus coal over the entire life cycle from source to use. However, the results of the life cycle analysis conducted in this report indicate that the EPA's upstream estimates of methane emissions from natural gas systems do not undercut the GHG advantage of natural gas over coal. Nevertheless, given the EPA's proposed new air quality rules that were released in July 2011, it is possible that the natural gas industry might need to mitigate many of the methane emissions associated with natural gas development in the near future and, specifically, with emissions related to the enhanced production of shale gas.

Beusse, R., Dunlap, C., Good, K., Hauck, E., McGhee-Lenart, R. & Narimatsu, J., 2013, *EPA Needs to Improve Air Emissions Data for the Oil and Natural Gas Production Sector*, US Environmental Protection Agency Report 13-P-0161, Office of the Inspector General. Available at: http://www.epa.gov/oig/reports/2013/20130220-13-P-0161.pdf

Overview

High levels of growth in the oil and natural gas (gas) production sector, coupled with harmful pollutants emitted, have underscored the need for EPA to gain a better understanding of emissions and potential risks from the production of oil and gas. However, EPA has limited directly measured air emissions data for air toxics and criteria pollutants for several important oil and gas production processes and sources, including well completions and evaporative ponds. Also, EPA does not have a comprehensive strategy for improving air emissions data for the oil and gas production sector; the agency did not anticipate the tremendous growth of the sector, and previously only allocated limited resources to the issue. EPA uses its National Emissions Inventory (NEI) to assess risks, track trends and analyze envisioned regulatory controls. However, oil and gas production emissions data in the 2008 NEI are incomplete for a number of key air pollutants. This hampers EPA's ability to accurately assess risks and air quality impacts from oil and gas production activities.

U.S. Environmental Protection Agency, 2013, *Greenhouse Gas Reporting Program: Petroleum and Natural Gas Systems 2011 Data Summary*, Office of Atmospheric Programs, Climate Change Division.

Overview

In February 2013, EPA released greenhouse gas data for petroleum and natural gas systems collected under the Greenhouse Gas Reporting Program (GHGRP) from the 2011 reporting year. These data represent a significant step forward with respect to better understanding greenhouse gas emissions from petroleum and natural gas systems. EPA is working to improve the quality of data from this sector and expects that the GHGRP will be an important tool for the agency and the public to analyze emissions, identify opportunities for improving the data and understand emissions trends. This presentation attempts to provide a summary of the reported data.

Howarth, R., Santoro, R. & Ingraffea, A., 2011, "Methane and the greenhouse-gas footprint of natural gas from shale formations," *Climatic Change*, letter, doi10.1007/s10584-011-0061-5.

Overview

This reports evaluates the greenhouse gas footprint of natural gas obtained by high-volume hydraulic fracturing from shale formations, focusing on methane emissions. Natural gas is composed largely of methane, and 3.6% to 7.9% of the methane from shale-gas production escapes into the atmosphere in venting and leaks over the lifetime of a well. These methane emissions are at least 30% more than and perhaps more than twice as great as those from conventional gas. The higher emissions from shale gas occur at the time wells are hydraulically fractured – as methane escapes from flowback return fluids – and during drill out following the fracturing. Methane is a powerful greenhouse gas, with a global warming potential that is far greater than that of carbon dioxide, particularly over the time horizon of the first few decades following emission. Methane contributes substantially to the greenhouse gas footprint of shale gas on shorter time scales, dominating it on a 20-year time horizon. The footprint for shale gas is greater than that for conventional gas or oil when viewed on any time horizon, but particularly so over 20 years. Compared with coal, the footprint of shale gas is at least 20% greater and perhaps more than twice as great on the 20-year horizon and is comparable when compared over 100 years.

Bylin, C., 2013, *Methane and Black Carbon Emissions from the Global Oil and Gas Industry*, US Environmental Protection Agency and the Global Methane Initiative.

Overview

This presentation seeks to demonstrate that significant potential exists to reduce methane and black carbon emissions from the oil and gas sector. Existing synergistic programs leverage country and company participation to reduce emissions by focusing on three particular areas/ideas: voluntary partnerships, project-level management and creating commitments or reduction targets pertaining to methane emissions. Building on existing synergies and expanding the current work being done in the area of GHG control, specifically with methane release, is crucial for the natural gas industry moving forward.

Global Methane Initiative, 2013, *Global Methane Emissions and Mitigation Opportunities*, prepared for the US Environmental Protection Agency.

Overview

Methane (CH_4) is a hydrocarbon and the primary component of natural gas. Methane is also a potent and abundant greenhouse gas, which makes it a significant contributor to climate change, especially in the near term (i.e. 10–15 years). Methane is emitted during the production and transport of coal, natural gas and oil. Understanding the emissions statistics associated with methane

release into the atmosphere is crucial for the ever-expanding US natural gas industry, especially with the advent of new horizontal drilling techniques that unlock gas from shale-rice geologic formations in various areas around the country.

Ritter, K., Emmert, A., Lev-On, M. & Shires, T., 2012, *Understanding Greenhouse Gas Emissions from Unconventional Natural Gas Production*, The American Petroleum Institute. Available at: http://www.epa.gov/ttnchie1/conference/ei20/session3/kritter.pdf

Overview

Natural gas comprises almost one fourth of all energy used in the United States. New technologies, sometimes referred to as "unconventional," have enabled the production of more natural gas and have expanded domestic energy reserves. Natural gas is generally recognized as a clean-burning fuel source, producing fewer greenhouse gas emissions per quantity of energy consumed than either coal or oil. However, a number of recent studies are raising questions as to the impact of these new production techniques – especially hydraulic fracturing – on the carbon footprint of natural gas. Current published assessments rely mostly on highly uncertain information provided in EPA's November 2010 technical support document for mandatory GHG reporting from petroleum and natural gas systems, and from information associated with EPA's Inventory of Greenhouse Gas Emissions and Sinks: 1990–2009. It is becoming increasingly important to document the GHG emissions associated with the different stages of natural gas production in order to demonstrate the continued environmental benefits of natural gas. Therefore, technically sound quantification and assessment of GHG emissions from its life cycle – from production to delivery to end users – is essential. This paper summarizes results from a technical review of the emissions data used to develop EPA's 2009 national inventory and the 2010 inventory updates.

Brown, S.P.A., Krupnick, A.J. & Walls, M.A., 2009, *Natural Gas: A Bridge to a Low-Carbon Future?* Resources for the Future and the National Energy Policy Institute, Issue Brief 09-11. Available at: http://www.rff.org/RFF/Documents/RFF-IB-09-11.pdf

Overview

Over the next 20 years, the United States and other countries seem likely to take steps toward a low-carbon future. Looking beyond this timeframe, many analysts expect nuclear power and emergent energy technologies – such as carbon capture and sequestration, renewable power generation and electric and plug-in hybrid vehicles – to hold the keys to achieving a sustainable reduction in carbon dioxide (CO2) emissions. In the meantime, however, many are discussing greater use of natural gas to reduce CO_2 emissions. Recent assessments suggest that the United States has considerably more recoverable natural gas in shale formations than was previously thought, given new drilling technologies that dramatically lower recovery cost. Because natural gas use yields CO_2 emissions that are about 45 percent lower per British thermal unit (Btu) than coal and 30 percent lower than oil, its apparent abundance raises the possibility that natural gas could serve as a bridge fuel to a future with reduced CO_2 emissions. Such a transition would seem particularly attractive in the electric power sector if natural gas were to displace coal.

IPIECA, 2013, *The expanding role of natural gas. Comparing life-cycle greenhouse gas emissions*. Available at: http://www.ipieca.org/publication/expanding-role-natural-gas-comparing-life-cycle-greenhouse-gas-emissions

Overview

Natural gas is enjoying a period of strong growth. Significantly increased resource estimates, and improvements in production and transport technologies allow it to fill an expanding role in energy supply, and in important demand sectors such as electricity generation. Almost all mitigation scenarios established by international or national research organizations, such as the International Energy Agency, the US Energy Information Administration and national laboratories, agree that the role of natural gas is expanding significantly, thanks to improved technologies employed in its extraction and supply. In the USA, a rapid increase in production from "unconventional" sources (e.g. shale) has resulted in an abundance of low-priced natural gas, encouraging a shift from coal to gas in power generation. Since natural gas is a fuel with inherently lower carbon content than coal, that shift has contributed to a significant decline in greenhouse gas emissions.

Hughes, D., 2011, *Life-Cycle Greenhouse Gas Emissions from Shale Gas Compared to Coal: An Analysis of Two Conflicting Studies*, Post Carbon Institute. Available at: http://www.postcarbon.org/report/390308-report-life-cycle-greenhouse-gas-emissions

Overview

Two studies with conflicting conclusions have recently been produced on full-cycle greenhouse gas emissions from shale gas production, one from scientists at Cornell University and another from a scientist at the National Energy Technology Laboratory (NETL). The Cornell study, published in a peer-reviewed journal, suggests that lifecycle GHG emissions from shale gas are 20–100% higher than coal on a 20-year timeframe basis, especially considering that 70% of natural gas consumption is not used

for electricity generation. The NETL study, presented in a talk at Cornell University and later posted on the NETL website, suggests, on an electricity-generation comparison basis, that natural gas base load has 48% lower GHG emissions than coal on a 20-year timeframe basis. The NETL comparison, however, does not single out shale gas, which is projected by the US Energy Information Administration to be the major source of natural gas supply growth going forward, nor does it consider the overall emissions from natural gas-fired electricity generation, focusing instead on the more efficient base load combined cycle component. When the assumptions of the NETL study are examined in detail and compared with the US EPA 2009 emissions inventory for natural gas, as well as to the likely ultimate production from shale gas wells, the resulting conclusions are not significantly different from the Cornell study. Shale gas full-cycle GHG emissions are higher than those of coal when comparing both the existing electricity generating fleets and best-in-class electricity generation technologies for both fuels over a 20-year timeframe basis, but are lower than those of coal on a 100-year timeframe basis. This has significant policy implications for utilizing natural gas as a "transition" fuel to a low carbon future in mitigating near-term GHG emissions.

Air/water/land impacts

Grubert, E. & Kitasei, S., 2010, *How Energy Choices Affect Fresh Water Supplies: A Comparison of U.S. Coal and Natural Gas*, Worldwatch Institute, Natural Gas and Sustainable Energy Initiative. Available at: http://www.worldwatch.org/system/files/BP2.pdf

Overview

Declining water availability is already limiting energy choices. Over the past decade, concerns about water availability have halted power plant construction or operation in the states of Arizona, California, Colorado, Georgia, Massachusetts, Missouri, New Mexico, North Carolina, Pennsylvania, Rhode Island, South Dakota, Tennessee, Texas and Washington. As state and local governments around the country plan their electricity generation mix for the coming years, they will need to consider the water dimension of their decisions. A shift from reliance on coal-fired steam-turbine generators to combined-cycle plants fueled by natural gas could have a profound effect on the power sector's water demands. NGCC plants consume one tenth to one half as much freshwater as conventional coal plants do to generate each unit of electricity, which provides a critical advantage in regions where water shortages present as urgent a concern as air pollution and climate change.

Adams, M.B, Ford, W.M., Schuler, T.M. & Thomas-Van Gundy, M., 2011, *Effects of Natural Gas Development on Forest Ecosystems*, Proceedings of the 17th Central Hardwood Forest Conference, Lexington, KY, (April 5–7, 2010), Newtown Square, PA, US Department of Agriculture, Forest Service, Northern Research Station, 219–226. Available at: http://www.nrs.fs.fed.us/pubs/gtr/gtr-p-78papers/23adamsp78.pdf

Overview

In 2004, an energy company leased the privately owned minerals that underlie the Fernow Experimental Forest in West Virginia. The Fernow, established in 1934, is dedicated to long-term research and in 2008, a natural gas well was drilled on the Fernow and a pipeline and supporting infrastructure were constructed. This study describes the impacts of natural gas development on the natural resources of the Fernow, and develops recommendations for landowners and land managers based on these experiences. Some of the effects (forest clearing, erosion, road damage) were expected and predictable, and some were unexpected (vegetation death from land application of fluids, an apparent increase in white-tailed deer presence). Although this is a case study, and therefore the results and conclusions are not applicable to all hardwood forests, information about gas development impacts is sufficiently rare that forest managers, research scientists and the concerned public can learn from the study.

STAC Workshop Report, 2013, *Exploring the Environmental Effects of Shale Gas Development in the Chesapeake Bay Watershed*, Pennsylvania State University, Scientific and Technical Advisory Committee, STAC Publication 13-01. Available at: http://www.chesapeake.org/pubs/297_Gottschalk2013.pdf

Overview

The purpose of this workshop was to engage scientists from across the nation in a review of the state of-the-science regarding shale gas development effects on the Chesapeake Bay. To date, many researchers have completed studies of various environmental effects, but a collective state-of-the science review of these studies has not been conducted. Without fully understanding the breadth of available scientific knowledge, the scientific community cannot adequately identify and prioritize future research needs. This workshop represents the first effort within the Chesapeake Bay Watershed to: 1) synthesize the collective research results available regarding shale gas development; and 2) identify the potential effects associated with shale gas development (e.g. water quality and quantity, land cover change) may pose to the Chesapeake Bay Watershed.

Pless, J., 2012, *Natural Gas Development and Hydraulic Fracturing: A Policymaker's Guide*, National Conference of State Legislatures. Available at: http://www.ncsl.org/documents/energy/frackingguide_060512.pdf

Overview

In recent years, technological advances in hydraulic fracturing and horizontal drilling have led to dramatic growth in natural gas development, with tremendous economic potential for state and local economies. Development currently is occurring in 32 states. Although hydraulic fracturing has been employed for decades, its use has rapidly increased in the past few years, and some states are taking steps to ensure that water and air quality are adequately protected during surface and subsurface natural gas development activities. This report provides an introduction to the domestic natural gas picture, explores the motivation behind state legislative involvement in natural gas regulation, and summarizes state legislation that is being developed to ensure safe, responsible development of this resource.

Murphy, S. & Ramudo, A., 2010, *Hydraulic Fracturing – Effects on Water Quality*, Cornell University, City and Regional Planning, CRP 5072. Available at: http://www.cce.cornell.edu/EnergyClimateChange/NaturalGasDev/Documents/City%20and%20Regional%20Planning%20Student%20Papers/CRP5072_Water%20Quality%20Final%20Report.pdf

Overview

Hydraulic fracturing development has the potential to impact the quality and quantity of water supply through land disturbance, toxic chemical usage near ground water supplies, disruption of groundwater flow pathways, increased water consumption, waste generation, release of methane pockets and other possible negative risks. The overall goal of this project is to identify the potential threats to the groundwater and surface water supplies in the New York State area. This report analyzes the costs associated with this process in order to determine what the future has in store for the feasibility of producing this natural gas. Finally, suggestions are offered regarding regulation for New York, implementations that should be set in place, possible ways to avoid certain risks and overall conclusions on the process of high-volume slick water horizontal hydraulic fracturing in the State of New York.

Rahm, B.G., Riha, S.J., Yoxtheimer, D., Boyer, E., Davis, K. & Belmecheri, S., 2012, *Environmental Water and Air Quality Issues Associated with Shale Gas Development in the Northeast.* Available at: http://www.marcellus.psu.edu/research/pdf/ChangingEnvironment.pdf

Overview

Development of Marcellus Shale for natural gas resources involves a variety of activities that can potentially impact environmental water and air quality. Some of these impacts are straightforward, while others involve more complicated relationships and/or could result from cumulative effects of multiple development activities over time and space. Through a review of research and experience in the Marcellus Shale region and elsewhere, the environmental water and air quality working group has identified potential environmental impacts and relates them to natural gas development activity. This study attempts to illustrate the state of scientific knowledge of these impacts, their causes and strategies for preventing and mitigating negative environmental consequences by providing a sample of annotated references and scientific literature. This report also identifies broad areas of particular research need, including interdisciplinary research (e.g. economics, sociology, governance) that could help stakeholders better understand environmental risk and define effective management strategies.

Gregory, K.B., Vidic, R.D. & Dzombak, D.A., 2011, "Water Management Challenges Associated with the Production of Shale Gas by Hydraulic Fracturing," *Elements Journal*, 7, 181–186. Available at: http://wp.cedha.net/wp-content/uploads/2012/11/Water-Management-Challenges-Associated-with-the-Production-of-Shale-Gas-by-Hydraulic-Fracturing.pdf

Overview

Development of unconventional, onshore natural gas resources in deep shale formations are rapidly expanding to meet global energy needs. Water management has emerged as a critical issue in the development of these inland gas reservoirs, where hydraulic fracturing is used to liberate the gas. Following hydraulic fracturing, large volumes of water containing very high concentrations of total dissolved solids (TDS) return to the surface. The TDS concentration in this wastewater, also known as "flowback," can reach five times that of seawater. Wastewaters that contain high TDS levels are challenging and costly to treat. Economical production of shale gas resources will require creative management of flowback to ensure protection of groundwater and surface water resources. Currently, deep-well injection is the primary means of management. However, in many areas where shale gas production will be abundant, deep-well injection sites are not available. With global concerns over the quality and quantity of freshwater, novel water management strategies and treatment technologies that will enable environmentally sustainable and economically feasible natural gas extraction will be critical for the development of this vast energy source.

Glassman, D., Wucker, M, Isaacman, T. & Champilou, C., 2011, *The Water-Energy Nexus: Adding Water to the Energy Agenda*, World Policy Institute Paper. Available at: http://www.worldpolicy.org/sites/default/files/policy_papers/THE%20WATER-ENERGY%20NEXUS_0.pdf

Overview

The competition between water and energy needs represents a critical business, security and environmental issue, but has not yet received the attention that it merits. Energy production consumes significant amounts of water; providing water, in turn, consumes energy. In a world where water scarcity is a major and growing challenge, meeting future energy needs depends on water availability and meeting water needs depends on wise energy policy decisions. As it pertains to natural gas, hydraulic fracturing has proven to be a game changer that could alter the entire energy mix of transportation fuels and electricity generation. The main water issue here involves pollution; however, additional research is needed on consumption, particularly in order to reflect substantial changes in the technology and its application to oil. Current data indicates that natural gas produced by hydraulic fracturing consumes seven times more water than conventional gas extraction but roughly the same amount of water as conventional oil drilling.

Natural gas liquefaction and maritime trade

Goncalves, C., 2013, *North American LNG Exports: How Disruptive For How Long?* 17th International Conference and Exhibition on Liquefied Natural Gas, Houston, Texas, April 1, 2013. Available at: http://www.gastechnology.org/Training/Documents/LNG17-proceedings/06_07-Christopher-Goncalves-Presentation.pdf

Overview

North American natural gas fundamentals and LNG exports confront the LNG industry with disruptive changes that create considerable uncertainties, risks and opportunities for LNG buyers, sellers, traders, investors and lenders. This study analyzes the impact and implications of North American natural gas fundamentals on North American LNG exports and global LNG markets and transactions. Such an analysis is conducted in order to provide conclusions regarding the implications for LNG investments, contracts, flexibility and trading.

Ditzel, K., Plewes, J. & Broxson, B., 2013, *US Manufacturing and LNG Exports: Economic Contributions to the US Economy and Impacts on US Natural Gas Prices*, prepared for the Dow Chemical Company. Available at: http://www.crai.com/uploadedFiles/Publications/CRA_LNG_Study_Feb2013.pdf

Overview

A manufacturing renaissance is under way in the United States, and it is being driven by a favorable natural gas price environment not seen for over a decade. Since 2010, there have been announcements of more than 95 major capital investments in the gas-intensive manufacturing sector representing more than US$90 billion in new spending and hundreds of thousands of new jobs all related to US domestic natural gas price advantage. The low gas prices are also sparking interest in large-scale LNG exports to higher-priced markets, such as Europe and Asia. While high volumes of LNG exports would increase profits to some participants in the oil and gas sector, the resulting increase in domestic gas prices may disrupt the growth in domestic manufacturing, natural gas vehicles and electricity generators. Consequently, the United States is faced with a critical policy decision: how to balance demand for LNG exports versus realization of domestic value added opportunities. To better understand the impacts of LNG exports, it is necessary to examine the importance of natural gas-intensive manufacturing to the US economy and how LNG exports could impact growth of other major demand sectors. This is especially important in light of the recently released NERA Report that finds LNG exports to be favorable to the economy along with recent comments submitted to the Department of Energy supporting unconstrained exports of our domestic natural gas resource. This report examines the major premises supporting unconstrained exports of LNG and shows that many of them are built upon false assumptions. Furthermore, this study finds that the manufacturing sector contributes more to the economy and is sensitive to the natural gas prices that will rise in an unconstrained LNG export scenario due to high global LNG demand and a non-flat domestic natural gas supply curve.

Ernst & Young, 2013, *Global LNG: Will new demand and new supply mean new pricing?* Oil and Gas Division. Available at: http://www.ey.com/Publication/vwLUAssets/Global_LNG_New_pricing_ahead/$FILE/Global_LNG_New_pricing_ahead_DW0240.pdf

Overview

A massive amount of new LNG capacity has been proposed – as much as 350 million (metric) tons per year – which, if all were built, would more than double current capacity by 2025. Even with reasonably strong demand growth, this implies growing supply-side competition and upward pressures on development costs and downward pressures on natural gas prices. Nevertheless, the very positive longer term outlook for natural gas is driving investment decisions, both in terms of buyers' willingness to sign long-term contracts and sellers' willingness to commit capital to develop the

needed projects. LNG demand growth is front-loaded, but in the wake of a capacity surge over the last few years, capacity growth is now back-loaded. What is being realized is a post-Fukushima squeeze, as well as a slowdown in near-term capacity additions, pointing to relatively tight markets over the next few years. LNG development costs have been rising at a torrid pace, and with LNG demand shifting to new, more price-sensitive customers just as the supply side battles with rising costs and increasing competition, sellers must adapt. The supply/demand magnitudes and dynamics aside, the biggest potential impacts are on LNG pricing: namely, will oil-price linkages continue to dominate global LNG contract pricing, will there be room for spot gas price linkages, and will divergent regional gas prices show signs of convergence? Going forward over the medium to longer term, there will most likely be a gradual but partial migration away from oil-linked pricing to more spot or hub-based pricing.

Sakmar, S., 2010, *The Globalization and Environmental Sustainability of LNG: Is LNG a Fuel for the 21st Century?* 2010 World Energy Congress, Montréal, Canada, (Sept. 12–16, 2010). Available at: http://www.worldenergy.org/documents/congresspapers/120.pdf

Overview

As the world enters the 21st century, policymakers around the world are grappling with issues related to energy security, energy poverty and an expected increase in future demand for all energy sources. At the same time, concerns about global climate change and reducing greenhouse gas emissions have also emerged as primary issues to be addressed as the world searches for a sustainable energy future. As a clean-burning fuel, many policy leaders have suggested that liquefied natural gas, LNG, can play an important role as the world struggles to meet growing energy demand using more environmentally sustainable fuels. Others claim that the safety and environmental impact, including life cycle emissions of LNG, may nullify any clean burning benefit LNG might otherwise provide. This paper analyzes whether LNG is a fuel for a sustainable energy future.

ICF International, 2013, U.S. *LNG Exports: Impacts on Energy Markets and the Economy*, prepared for the American Petroleum Institute. Available at: http://www.api.org/~/media/Files/Policy/LNG-Exports/API-LNG-Export-Report-by-ICF.pdf

Overview

The main conclusion of this report is that LNG exports will have net gains to the economy, in terms of GDP and employment gains. LNG exports are expected to have net positive effects on US employment, with projected net job growth of between 73,100 to 452,300 jobs on average between 2016 and 2035, including all economic multiplier effects. Manufacturing job gains average between 7,800 and 76,800 net jobs between 2016 and 2035, including 1,700–11,400 net job gains in the specific manufacturing sectors that include refining, petrochemicals and chemicals. In terms of per Bcfd in LNG exports, the study concludes that the net effect on US employment is expected to also be positive with net job growth of 25,000 to 54,000 average annual jobs per one Bcfd of LNG exports, including all economic multiplier effects.

International Gas Union, 2011, *World LNG Report 2011*. Available at: http://www.igu.org/gas-knowhow/publications/igu-publications/LNG%20Report%202011-web-7.pdf

Overview

LNG trade grew stronger than anticipated in 2011. Since 2006, five new countries started LNG exports and ten new markets began importing LNG. At the same time, the price differential between oil-linked, spot and Henry Hub prices for LNG has created new opportunities and challenges for the industry. Demand for LNG reached new heights in 2011, primarily due to sharp increase in demand from Japan in the wake of that country's March 2011 natural catastrophe and the ensuing nuclear disaster at the Fukushima nuclear power plant. Strong demand in the UK, China and India, augmented by increased volumes from emerging new markets, further tightened the world's LNG market. Though the unconventional gas boom in the United States was thought to prove detrimental for an industry that had spent the previous decade building liquefaction capacity, growing demand elsewhere and high oil prices saw LNG prices reaching record highs.

Henderson, J., 2012, *The Potential Impact of North American LNG Exports*, The Oxford Institute for Energy Studies. Available at: http://www.oxfordenergy.org/wpcms/wp-content/uploads/2012/10/NG-68.pdf

Overview

Expectations that the world's three major regional gas markets would become ever more closely linked via flexible LNG supply were put "on hold" with the emergence of the US shale phenomenon from circa 2008 onwards as North America, requiring minimal LNG imports, effectively de-linked from the rest of the gas world. At present the divergence in price between the US Henry Hub, European hub or oil-indexed prices and Asian LNG JCC contract prices has never been so marked. However, just as "nature abhors a vacuum," trade and arbitrage dynamics will inevitably seek to exploit such price differences and, in doing so, reduce them. Beyond 2015, new sources of LNG supply from Australia, North America and East Africa will accelerate such arbitrage activity, although the scale and timing of these new "waves" of LNG are subject to considerable uncertainty.

Electric generation and transportation

Aspen Environmental Group, 2010, *Implications of Greater Reliance on Natural Gas for Electricity Generation*, prepared for the American Public Power Association. Available at: http://www.publicpower.org/files/PDFs/ImplicationsOfGreaterRelianceOnNGforElectricityGeneration.pdf

Overview

This report examines the impacts on natural gas and deliveries to electric utilities should the rules limiting utility emissions of carbon or other pollutants result in a shift away from coal towards using more natural gas to generate electricity. The report begins with a review of the natural gas industry for those who are less familiar with it. It then covers demand, supply, transmission and storage infrastructure, and operational changes that will need to be made by units switching from coal to gas. It then examines the economics of switches from coal to gas. An understanding of these issues is needed if the electricity industry should need substantially more gas than several studies have suggested. If substantially more gas is needed, then a number of changes will need to be made by both the gas and electricity industries: changes such as massive infrastructure additions, changes to nominating and balancing services, changes to curtailment rules, and changes to subscription levels on interstate pipelines, for starters. The ultimate purpose of the study is to identify those implications so that policymakers can take them into account in deciding what regulations to adopt, and utilities can take them into account in making selections about what resources to use in providing electricity to their customers.

Knittel, C.R., 2012, *Leveling the Playing Field for Natural Gas in Transportation*, Brookings, The Hamilton Project. Available at: http://www.brookings.edu/research/papers/2012/06/13-transportation-knittel

Overview

Technological advances in horizontal drilling deep underground have led to large-scale discoveries of natural gas reserves that are now economical to access. This, along with increases in oil prices, has fundamentally changed the relative price of oil and natural gas in the United States. As of December 2011, oil was trading at a 500 percent premium over natural gas. This ratio has increased over the past few months. The discovery of large, economically accessible natural gas reserves has the potential to aid in a number of policy goals related to energy. Natural gas can replace oil in transportation through a number of channels. However, the field between natural gas as a transportation fuel and petroleum-based fuels is not level. Given this uneven playing field, left to its own devices, the market is unlikely to lead to an efficient mix of petroleum- and natural gas-based fuels. This paper presents a pair of policy proposals designed to increase the nation's energy security, decrease the susceptibility of the US economy to recessions caused by oil-price shocks, and reduce greenhouse gas emissions and other pollutants. First, this study proposes improving the natural gas fueling infrastructure in homes, at local distribution companies, and along long-haul trucking routes. Second, this study offers steps to promote the use of natural gas vehicles and fuels.

Center for Climate and Energy Solutions, 2012, *Natural Gas Use in the Transportation Sector*, University of Texas Energy Institute and the Energy Management and Innovation Center.

Overview

Natural gas is the most flexible of the three primary fossil fuels (coal, petroleum, natural gas) used in the United States and accounted for 25 percent of the total energy consumed nationwide in 2009. In spite of the major roles that natural gas plays in electricity generation as well as in the residential, commercial and industrial sectors, it is not commonly used for transportation. In total, the US transportation sector used 27.51 quadrillion Btus of energy in 2010, of which 25.65 quadrillion Btus came from petroleum and just 0.68 quadrillion Btus came from natural gas (93 percent and 3 percent of the sector, respectively). Natural gas used in the transportation sector resulted in the emission of around 34.5 million metric tons of carbon dioxide equivalent (CO_2e) in 2009. A variety of vehicle technologies available today allows natural gas to be used in light-, medium-, and heavy-duty vehicles. Most commonly, natural gas is used in a highly pressurized form as compressed natural gas (CNG) or as liquefied natural gas (LNG). While CNG and LNG are ultimately combusted in the vehicle, it can also power vehicles in other ways. It can be converted into liquid fuel that can be used in conventional vehicles, power fuel cell vehicles or be used in the production of electricity for electric vehicles. Despite the existence of these technologies, only about 117,000 of the more than 250 million vehicles on the road in 2010 (about .05%), were powered directly by natural gas (not including electric vehicles). Of these, the majority of natural gas vehicles are buses and trucks. The recent relative cost differential between natural gas and oil as a fuel source, however, has increased interest in expanding the use of natural gas beyond just buses and trucks thus representing a much broader market opportunity.

Kaplan, S.M., 2010, *Displacing Coal with Generation from Existing Natural Gas-Fired Power Plants*, Congressional Research Service. Available at: http://fairbankspipelinecompany.com/pdf/Displacing_Coal_with_Gas.pdf

Overview

Reducing carbon dioxide emissions from coal plants is a focus of many proposals for cutting greenhouse gas emissions. One option is to replace some coal power with natural gas generation by increasing the power output from currently underutilized natural gas plants. This report provides an overview of the issues involved in displacing coal-fired generation with electricity from existing natural gas plants. This is a complex subject and the report does not seek to provide definitive answers. The report aims to highlight the key issues that Congress may want to consider in deciding whether to rely on, and encourage, displacement of coal-fired electricity with power from existing natural gas plants. The report finds that the potential for displacing coal by making greater use of existing gas-fired power plants depends on numerous factors. Certain factors include: 1) the amount of excess natural gas-fired generating capacity available; 2) the current operating patterns of coal and gas plants, and the amount of flexibility power system operators have for changing those patterns; 3) whether or not the transmission grid can deliver power from existing gas power plants to loads currently served by coal plants; and 4) whether there is sufficient natural gas supply, and pipeline and gas storage capacity, to deliver large amounts of additional fuel to gas-fired power plants. Finally, focusing on such factors also begs the question of the cost of a coal displacement by gas policy, and the impacts of such a policy on the economy, region and states that could change in the future as load grows. Therefore a full analysis of the potential for gas displacement of coal must take into account future conditions, not just a snapshot of the current situation.

Cowart, R., 2011, *Interdependence of Electricity System Infrastructure and Natural Gas Infrastructure*, memorandum from Electricity Advisory Committee to US Department of Energy. Available at: http://energy.gov/sites/prod/files/EAC%20-%20Interdependence%20of%20Electricity%20System%20Infrastructure%20and%20Natural%20Gas%20Infrastructure%20Oct%202011.pdf

Overview

The US Energy Information Administration reported in its July 5, 2011 publication, Today in Energy, that at the end of 2010, natural gas-fired generators constituted 39% of the nation's total electric generation capacity. Almost 237 GW of natural gas-fired generation capacity came online between 2000 and 2010, equaling 81% of the total amount of generation capacity added during that time period. Furthermore, according to EIA data, natural gas-fired generation's share of US electricity generation during the past ten years has grown 44%. This study analyzes the necessary steps that must be taken in order to realize the Obama Administration's energy goals and how best to catalyze the interdependence of the nation's electric infrastructure and natural gas infrastructure in order to determine where greater reliability and efficiencies may be achieved.

Shadhidehpour, J., Fu, Y. & Weidman, T., 2005, *Impact of Natural Gas Infrastructure on Electric Power Systems*, Proceedings of the IEEE 93(5), 1042–1056.

Overview

The restructuring of electricity has introduced new risks associated with the security of natural gas infrastructure on a significantly large scale, which entails changes in physical capabilities of pipelines, operational procedures, sensors and communications, contracting (supply and transportation) and tariffs. This paper discusses the essence of the natural gas infrastructure for supplying the ever-increasing number of gas-powered units and uses security-constrained unit commitment to analyze the short-time impact of natural gas prices on power generation scheduling. The paper analyzes the impact of natural gas infrastructure contingencies on the operation of electric power systems. Furthermore, the paper examines the impact of renewable sources of energy such as pumped-storage units and photovoltaic/battery systems on power system security by reducing the dependence of electricity infrastructure on the natural gas infrastructure. A modified IEEE 118-bus with 12 combined-cycle units is presented for analyzing the gas/electric interdependency.

Logan, J., Heath, G., Macknick, J., Paranos, E., Boyd, W. & Carlson, K., 2012, *Natural Gas and the Transformation of the U.S. Energy Sector: Electricity*, Joint Institute for Strategic Energy Analysis, Technical Report NREL/TP-6A50-55538. Available at: http://www.nrel.gov/docs/fy13osti/55538.pdf

Overview

Domestic natural gas production was largely stagnant from the mid-1970s until about 2005. Planning had been under way by the early 2000s to construct about 40 liquefied natural gas import terminals along the US coast to meet anticipated rising demand. However, beginning in the late 1990s, advances linking horizontal drilling techniques with hydraulic fracturing allowed drilling to proceed in shale and other formations at much lower cost. The result was a slow, steady increase in unconventional gas production. What remains unclear, however, is whether natural gas will continue to exert such a dramatic impact on the power sector and the overall US economy. If natural gas prices continue to stay at, or near, historically low levels, then a self-correction in the shale gas boom may occur. Due to price concerns, some companies have shifted away from drilling for dry gas and instead are focusing on plays that provide natural gas liquids. The ongoing debate is about what price is needed for unconventional natural gas production to be more sustainable over the medium term as it concerns electric power generation.

Marbek, 2010, *Study of Opportunities for Natural Gas in the Transportation Sector*, prepared for Natural Resources Canada. Available at: http://www.xebecinc.com/pdf/Marbek-NGV-Final-Report-April-2010.pdf

Overview

This report provides an assessment of the potential use of natural gas as an alternative fuel across the transportation sector. This includes the on-road and off-road, marine, rail and indoor equipment sectors. The report has been prepared for the Fuels Policy and Programs (FPP) division of Natural Resources Canada (NRCan). The objectives of this study were: 1) to explore and analyze the potential for the use of natural gas in support of the Government of Canada's policy objectives for the transportation sector; 2) to conduct a study that includes research and information gathering to inform the development of a Canadian strategy for the use of natural gas in the transportation sector; and 3) to identify and explore other potential future applications for natural gas in the Canadian context within the transportation sector. A preliminary assessment of previous, existing and future market and technology trends in North America and more specifically in Canada and consultation with natural gas vehicle (NGV) industry stakeholders showed that the more promising NGV market segments are likely to consist of the following: 1) heavy duty and medium duty, including line haul trucking (fleets); 2) return-to-base trucks; 3) transit buses; 4) refuse trucks; and 5) light duty fleets. These segments were selected to be included in the study of financial, environmental and achievable potentials.

North American Electric Reliability Corporation, 2013, *2013 Special Reliability Assessment: Accommodating an Increased Dependence on Natural Gas for Electric Power, Phase II: A Vulnerability and Scenario Assessment for the North American Bulk Power System*.

Overview

The combination of growth in natural gas demand within the electricity sector and its changing status among the gas consuming sectors continues to significantly increase the interdependencies between the gas and electricity industries. As a result, the interface between the two industries has become the focus of industry discussions and policy considerations. In its effort to maintain and improve the reliability of North America's bulk power system (BPS), NERC examined this issue in detail and developed recommendations for the power industry. These recommendations will help improve existing coordination between the gas and electricity sectors and facilitate the reliable operation of the two industries. Addressing interdependence issues requires a coordinated approach for minimizing the risks and vulnerabilities on bulk power and gas systems. This report focuses on the electric industry's dependence on natural gas and offers recommendations for reducing BPS exposure to increasing natural gas dependency risks.

Gallagher, M., 2012, *The Future of Natural Gas as a Transportation Fuel: Findings of the NPC Study*, a presentation for the 2012 NGV conference, Schaumburg, IL, (Oct. 5, 2012). Available at: http://www.cleanvehicle.org/conference/2012/NGVCS-Friday/GallagherNPCFutureTransportationFuelsStudy.pdf

Overview

This study examines opportunities to accelerate future transportation fuels prospects for natural gas through 2050 for auto, truck, air, rail and waterborne transport. Addressing fuel demand, supply, infrastructure and technology includes analyzing certain factors related to energy efficiency, environmental issues such as carbon emissions, land impacts, and water impacts, as well as energy security concerns and efforts to improve economic competitiveness.

Lee, A., Zinaman, O. & Logan, J., 2012, *Opportunities for Synergy Between Natural Gas and Renewable Energy in the Electric Power and Transportation Sectors*, National Renewable Energy Laboratory, Technical Report NREL/TP-6A50-56324. Available at: http://www.nrel.gov/docs/fy13osti/56324.pdf

Overview

Use of both natural gas and renewable energy has grown significantly in recent years. Both forms of energy have been touted as key elements of a transition to a cleaner and more secure energy future, but much of the current discourse considers each in isolation or concentrates on the competitive impacts of one on the other. This paper attempts, instead, to explore potential synergies of natural gas and renewable energy in the US electric power and transportation sectors. The first section of this paper offers nine platforms for dialogue and partnership between the natural gas and renewable energy industries, including development of hybrid technologies, energy system-integration studies, analysis of future energy pathways and joint myth-busters initiatives. Section two provides a brief summary of recent developments in natural gas and renewable energy markets. It is intended mainly for non-experts in either energy category. Section three, on the electric power sector, discusses potential complementarities of natural gas and renewable energy from the perspective of electricity portfolio risk and also presents several current market design issues that could benefit from collaborative engagement. Finally, section four, on the transportation sector, highlights the technical and economic characteristics of an array of alternative

transportation technologies and fuels. Opportunities for natural gas and renewable energy transportation pathways are discussed, as are certain relevant transportation policies.

Pipeline infrastructure, processing and storage

Yardley Associates, 2012, *Gas Distribution Infrastructure: Pipeline Replacement and Upgrades, Cost Recovery Issues and Approaches*, prepared for The American Gas Foundation. Available at: http://www.gasfoundation.org/ResearchStudies/AGF-infrastructure-2012.htm

Overview

Natural gas local distribution companies (LDCs) and federal and state regulators are resolutely committed to the safe and reliable operation of natural gas transmission and distribution networks. This commitment is demonstrated by continuous improvements in critical LDC business processes including incident prevention, inspections and monitoring, and by replacement of network facilities subject to leaks or material failure. Facilities most likely to require replacement on a priority basis are pipe and other facilities constructed using unprotected steel and cast iron pipe, certain early vintage plastic pipe, pipe fittings and other infrastructure that is leak-prone. Approximately 9% of distribution mains services in the United States are constructed of materials that are considered leak-prone. At the current pace of replacement, it will take up to three decades or longer for many operators to replace this infrastructure. Investments in new technologies and advancements in system design, monitoring, control and maintenance methods provide additional opportunities to enhance the reliability and safety of gas distribution infrastructure.

Center for Climate and Energy Solutions, 2012, *US Natural Gas Infrastructure*, The University of Texas at Austin, Energy Management and Innovation Center.

Overview

The United States has the world's most extensive infrastructure for transporting natural gas from production and importation sites to consumers all over the country. This transport infrastructure is made up of three main components: gathering pipelines, transmission pipelines and distribution pipelines. Though fundamentally similar in nature, each of these components is designed for a specific purpose, operating pressure and condition and length. This report examines the increasing demand for natural gas in the power, transportation and industrial sectors as well as in residential and commercial buildings and makes recommendations for methods to allow for significant system expansion to take advantage of potential greenhouse gas emission reductions, cost savings and energy security benefits, while at the same time minimizing methane leakage.

The INGAA Foundation, Inc., 2013, *Building Interstate Natural Gas Transmission Pipelines: A Primer*, INGAA Foundation Report 2013.01. Available at: http://www.ingaa.org/File.aspx?id=19618

Overview

This primer was written to explain how interstate natural gas pipelines are constructed, from the planning stages to completion. It is designed to help the reader understand what is done during each step of construction, how it is done, the types of equipment used and the types of special practices employed in commonly found construction situations. It also describes practices and methods used to protect workers, ensure safe operation of equipment, respect landowner property, protect the environment and ensure safe installation of the pipeline and appurtenances. Interstate natural gas pipelines are the pipelines that transport natural gas across state lines. These pipelines typically carry significantly larger volumes than gathering lines (pipelines within a field that bring natural gas from production wells to a processing plant), intrastate pipelines (those that transport natural gas within a state) or distribution pipelines (those that provide gas to homes and businesses). Because this document focuses on interstate natural gas pipelines, the regulatory environment discussed largely is federal because federal agencies, including the Federal Energy Regulatory Commission (FERC) and the Pipeline and Hazardous Materials Safety Administration (PHMSA), among others, are the primary regulators of these pipelines.

Peters, G., 2012, *Gas and Electric Infrastructure Interdependency Analysis*, prepared for the Midwest Independent Transmission System Operator.

Overview

The Midwest and the Midcontinent Independent System Operator (MISO) region have become a crossroads in the North American natural gas market. There is an extensive network of over 25 pipelines that transport natural gas from nearly all major supply basins in North America to and around the MISO region. However, natural gas flows in the MISO region have seen significant changes lately. Combined with shale gas developments nationwide, pipeline infrastructure projects have created a major paradigm shift and domino effect of altering traditional North American natural gas market flow patterns. For example, the traditional south to north pipeline capacity (Gulf and southwest gas) and north to south pipeline follows (Canadian gas) have been altered by the Rockies Express Pipeline ("REX") and shale gas developments.

New pipeline infrastructure projects are concentrated in the expanding shale-rich oil, natural gas liquids (NGLs) and natural gas production areas throughout the United States and Canada. This layer of infrastructure is primarily providing access to local markets and interconnections through the interstate natural gas pipeline network. This trend will continue as new production opportunities develop in areas that have been overlooked for re-work, undiscovered or become economical. In many of the most popular shale basins, prices and production are being pressured by a lack of pipeline capacity. "Take-away" capacity from the Permian basin shale region in west Texas is constrained as is the Eagle Ford shale region in south central Texas. The Marcellus shale region in the Northeast is highly constrained when it comes to moving natural gas liquids to market. The clear majority of all new gas pipeline projects are being driven by shale gas projects, as producers tap into oil and NGL-rich shale and work to remain financially viable in light of lower natural gas prices.

Ware, T., 2010, *Accurate Semi-Lagrangian Time Stepping For Gas Storage Problems*, presentation at Fields Institute, Toronto, (Nov. 4, 2010). Available at: http://www.utstat.utoronto.ca/sjaimung/Fields-MITACS-ASMF/10-11/TonyWare.pdf

Overview

This report analyzes the storage of natural gas using a semi-Lagrangian approach that is fundamentally an approach to time discretization. As such, it can be combined with any desired discretization in the other dimensions. Additionally, second order accuracy can be achieved for certain kinds of stochastic optimal control problems. Although seasonality is not discussed, this dimension of natural gas storage can be incorporated without altering the format of the chosen equations, although care should be taken to limit the amount of time spent determining certain mathematic storage functions. Multifactor models are essential for any realistic storage valuation: unless the market model is rich enough to capture the variability of different calendar spreads, much of the value will be lost. Other challenges involve addressing some of the considerations faced by actual storage managers: such as determining the optimal policy when the storage facility is used as a partial hedge for existing risks.

Thompson, M., Davison, M. & Rasmussen, H., 2009, "Natural Gas Storage Valuation and Optimization: A Real Options Application," ***Naval Research Logistics*** 56(3), 226–238.

Overview

This paper presents an algorithm for the valuation and optimal operation of natural gas storage facilities. Real options theory is used to derive nonlinear partial-integro-differential equations (PIDEs) for the valuation and optimal operating strategies. The equations are designed to incorporate a wide class of spot price models that can exhibit the same time-dependent, mean-reverting dynamics and price spikes as those observed in most energy markets. Particular attention is paid to the operational characteristics of real storage units, these characteristics include: working gas capacities, variable deliverability and injection rates and cycling limitations. This paper tries to illustrate a model with a numerical example of a salt cavern storage facility that clearly shows how a gas storage facility is like a financial straddle with both put and call properties.

Gas Infrastructure Subgroup of the Resource & Supply Task Group, 2011, *Natural Gas Infrastructure*, National Petroleum Council. Available at: http://www.npc.org/Prudent_Development-Topic_Papers/1-9_Natural_Gas_Infrastructure_Paper.pdf

Overview

The US natural gas infrastructure system is comprised of a network of buried transmission, gathering and local distribution pipelines, natural gas processing, liquefied natural gas and storage facilities. Natural gas gathering and processing facilities are necessarily located close to sources of production. They gather gas from producing wells and remove water, volatile components and contaminants before the gas is fed into transmission pipelines, which transport natural gas from producing regions to consuming regions. Storage facilities are located in both production areas and near market areas, subject to geological limitations and market forces. This report provides an extensive overview of the natural gas infrastructure in the United States.

Platts, 2012, *The North American Gas Value Chain: Developments and Opportunities*, Platts Price Group, Power, Oil and Petrochemical Divisions, Special Report. Available at: http://www.platts.com/IM.Platts.Content/InsightAnalysis/IndustrySolutionPapers/GasValueChain.pdf

Overview

The exploration and proliferation of shale gas deposits in North America have changed the face of regional natural gas and natural gas liquids industries. The groundswell in domestic onshore supplies has reversed typical supply flows in the US, with shale plays such as the Marcellus and potentially the Utica opening up the possibility the US Northeast could become a net exporter of gas in a few years. The current paradigm shift that has positioned the US now as a potential net exporter of natural gas represents a complete reversal from the concerns a decade ago that spurred the construction of new liquefied natural gas import terminals along US coastlines. Many of those same terminals are now re-exporting and/or seeking licenses to export gas. US natural gas producers

now have the ability to bring more gas to the domestic market than the market can absorb. The shifting ground has extended further down the supply chain as well. Natural gas liquids margins, not natural gas itself, are driving development in US shale plays, and with natural gas prices at the Henry Hub benchmark at close to historic lows just below the US$3/MMBtu mark, these wet, or high Btu, plays should continue to drive production growth. Furthermore, the proliferation in liquids promises to shift the US petrochemical industry into a new "golden age," as supply growth throughout the gas value chain promises plentiful feedstock supply for the downstream industry. As the crude-to-gas ratio and the fractionation spread between ethane and natural gas, or "frac spread" rose to record highs in late 2011, expansions and new construction projects, for olefin-producing steam crackers, primarily ethane-fed and ethylene producing, have progressed in the US at a rate of growth not seen for nearly three decades.

Stakeholder engagement, public perceptions and regulatory oversight

43 CFR Part 3160, 2012, *Oil and Gas; Hydraulic Fracturing on Federal and Indian Lands*, Department of Interior, Bureau of Land Management.

Overview

The Bureau of Land Management (BLM) oversees approximately 700 million subsurface acres of federal mineral estate and 56 million subsurface acres of Indian mineral estate across the United States. Thus, BLM is moving forward with a proposed rulemaking in order to modernize its management of hydraulic fracturing operations by ensuring that those conducted on the public mineral estate follow certain best practices. These best practices include: 1) public disclosure of chemicals used in hydraulic fracturing operations on federal and Indian lands; 2) confirmation that wells used in fracturing operations meet appropriate construction standards; and 3) a requirement that operators put in place appropriate plans for managing flowback waters from fracturing operations.

Clark, C., Burnham, A., Harto, C. & Homer, R., 2012, *Hydraulic Fracturing and Shale Gas Production: Technology, Impacts, and Policy*, Argonne National Laboratory, Environmental Science Division, ANL/EVS/R-12-5. Available at: http://www.afdc.energy.gov/uploads/publication/anl_hydraulic_fracturing.pdf

Overview

Hydraulic fracturing is a key technique that has enabled the economic production of natural gas from shale deposits, or plays. The development of large-scale shale gas production is changing the US energy market, generating expanded interest in the usage of natural gas in sectors such as electricity generation and transportation. At the same time, there is much uncertainty of the environmental implications of hydraulic fracturing and the rapid expansion of natural gas production from shale plays. The goal of this white paper is to explain the technologies involved in shale gas production, the potential impacts of shale gas production, and the practices and policies currently being developed and implemented to mitigate these impacts. In terms of regulations on natural gas, the Energy Policy Act of 2005, specifically section 322, limits EPA's authority on hydraulic fracturing issues by excluding from its regulatory authority under the Safe Drinking Water Act the underground injection of any fluid, other than diesel fuels, pursuant to hydraulic fracturing operations. Several congressional efforts have been made to end this exemption, including H.R. 1084, Fracturing Responsibility and Awareness of Chemicals Act of 2011, and S. 587, which is similarly titled. Meanwhile, other regulatory efforts have been under way on the federal, state and local levels. This paper attempts to illuminate current regulatory efforts at these various levels of government.

Deloitte, 2012, *Deloitte Survey – Public Opinions on Shale Gas Development: Positive Perceptions Meet Understandable Wariness*. Available at: http://www.deloitte.com/assets/Dcom-UnitedStates/Local%20Assets/Documents/Energy_us_er/us_er_ShaleSurveypaper_0412.PDF

Overview

The sudden rise in shale gas production, often in areas where residents are unfamiliar with energy exploration and production activity, has brought new public attention to and concern about shale gas extraction methods, and their impact on the communities where production is taking place. To look beyond the heated rhetoric on natural gas extraction that often dominates media coverage, the Deloitte Center for Energy Solutions commissioned a survey, polling Americans about their attitudes toward shale gas development in the US. The survey included samples of adults living in regions long accustomed to oil and gas production activity as well as adults living in states where energy production is a relatively new phenomenon.

Brady, W.J., 2012, *Hydraulic Fracturing Regulation in the United States: The Laissez-Faire Approach of the Federal Government and Varying State Regulations*, University of Denver, Sturm College of Law. Available at: http://www.law.du.edu/documents/faculty-highlights/Intersol-2012-HydroFracking.pdf

Overview

The United States contains vast amounts of oil and natural gas in shale formations. For decades, the US oil and gas industry

has employed the process of hydraulic fracturing to exploit these natural resources. The process raises significant concerns about air and groundwater pollution, which has led to a polarizing, often heated public debate that continues to this day, and will likely continue for the foreseeable future. Current US federal regulation of hydraulic fracturing, and oil and gas industry extraction operations, largely consists of a string of ad hoc exemptions and little oversight. The bulk of the regulatory responsibility is given to the states, and these regulations vary widely in their complexity and level of protection of human health and the environment. New research findings, proposed regulations, and allegations of groundwater contamination are released on an almost daily basis. With newly proposed federal regulations, studies being conducted by the states, the federal government, public interest NGOs and mounting pressure from environmental groups, the state of hydraulic fracturing regulation in the US is, quite literally, up in the air. This paper seeks to tie together the current regulatory environment concerning natural gas development in the US and makes future projections about how that environment might evolve in the future.

Pew Research Center for the People and the Press, 2012, *Those Aware of Fracking Favor Its Use: As Gas Prices Pinch, Support for Oil and Gas Production Grows*, (Mar. 19). Available at: http://www.people-press.org/files/legacy-pdf/3-19-12%20Energy%20release.pdf

Overview

At a time of rising gas prices, the public's energy priorities have changed. More Americans continue to view the development of alternative energy sources as a higher priority than the increased production of oil, coal and natural gas, but the gap has narrowed considerably over the past year. Moreover, support for allowing more offshore oil and gas drilling in US waters, which plummeted during the 2010 Gulf of Mexico oil spill, has recovered to pre-spill levels. Nearly 65% favor allowing increased offshore drilling, up from 57% a year ago and 44% in June 2010, during the Gulf spill. The latest national survey by the Pew Research Center for the People and the Press, conducted March 7–11, 2012, among 1,503 adults, finds that 52% say the more important priority for addressing the nation's energy supply is to develop alternative sources, such as wind, solar and hydrogen technology. On the other hand, 39% see expanding the exploration and production of oil, coal and natural gas as the greater priority.

Brown E., Hartman, K. Borick, C., Rabe, B.G. & Ivacko, T., 2013, *The National Surveys on Energy and Environment, Public Opinion on Fracking: Perspectives from Michigan and Pennsylvania*, Gerald R. Ford School of Public Policy, University of Michigan. Available at: http://issuu.com/closup/docs/nsee-fracking-fall-2012/1?e=1661894/2440099

Overview

This report presents the views of Michigan and Pennsylvania citizens on issues related to the extraction of natural gas through hydraulic fracturing, which is more commonly known as "fracking." Hydraulic fracturing and new horizontal drilling techniques are creating significant opportunities to expand natural gas production across the United States. The absence of comprehensive federal legislation regarding hydraulic fracturing has placed the regulation of unconventional gas drilling primarily within the purview of state and local governments. This report examines public opinion in Michigan and Pennsylvania on a series of issues concerning the impact of fracking on the economy, environmental protection and information disclosure. Pennsylvania and Michigan have been selected as the focus of this report because they represent states with varied levels of hydraulic fracturing within their borders. Pennsylvania has emerged as one of the nation's leaders in terms of the number of hydraulic fracturing sites with extensive drilling occurring in the commonwealth, and also has high levels of public debate and policy development related to this issue. Conversely, fracking has just begun to develop on a large scale within Michigan with corresponding public engagement around the matter in its early stages. These differences present a valuable opportunity to examine where the publics in these two states stand on an array of issues related to fracking.

Willits, F.K., Braiser, K., Filteau, M.R., McLaughlin, D.K., Ooms, T., Tracewski, S. & Stedman, R.C., 2011, *Pennsylvania Residents' Perceptions of Natural Gas Development in the Marcellus Shale*, Penn State University, Cornell University, and the Institute for Public Policy and Economic Development, http://energy.wilkes.edu/PDFFiles/Public%20Opinion/respondentcharacter2.pdf

Overview

The presence of vast natural gas reserves in the region known as the Marcellus Shale has been known for decades. However, recent emphasis on domestic energy production, coupled with technological advancements that make the recovery of these deep natural gas reserves cost effective, have led to increasing interest and activity in developing these resources. Most of the counties within the region are rural in nature, and the potential impact of widespread gas development is profound. Large-scale energy development can bring increasing economic investments, jobs and population growth. At the same time, there are both environmental and social risks. The hydro-fracturing process used to free the embedded gas uses large quantities of water and requires treatment/disposal of flowback water. The drilling

process requires clearing land, often in forests or on farms, altering ecosystems, wildlife habitats and landscape amenities. The influx of new workers and residents may stress community services and infrastructure, shift community power structures, and alter community interactions, norms and values. Given these potential changes how do people living in the region view the natural gas industry developing in their area? To address this question, a household survey of residents in the Marcellus Shale area in Pennsylvania was conducted in winter of 2009–2010 to assess residents' knowledge and perceptions of the Marcellus natural gas industry during the early stages of its development.

US Department of Energy, 2009, *Modern Shale Gas Development in the United States: A Primer*, Office of Fossil Energy, National Energy Technology Laboratory. Available at: http://www.netl.doe.gov/technologies/oil-gas/publications/epreports/shale_gas_primer_2009.pdf

Overview

The development and production of oil and gas in the US, including shale gas, are regulated under a complex set of federal, state and local laws that address every aspect of exploration and operation. All of the laws, regulations and permits that apply to conventional oil and gas exploration and production activities also apply to shale gas development. The US Environmental Protection Agency administers most of the federal laws, although development on federally owned land is managed primarily by the Bureau of Land Management and the US Forest Service. In addition, each state in which oil and gas is produced has one or more regulatory agencies that permit wells, including their design, location, spacing, operation and abandonment, as well as environmental activities and discharges, including water management and disposal, waste management and disposal, air emissions, underground injection, wildlife impacts, surface disturbance and worker health and safety. Many of the federal laws are implemented by the states under agreements and plans approved by the appropriate federal agencies.

Groat, C.G. & Grimshaw, T.W., 2012, *Fact-Based Regulation for Environmental Protection in Shale Gas Development*, The University of Texas at Austin, Energy Institute. Available at: http://barnettprogress.com/media/ei_shale_gas_regulation120215.pdf

Overview

Natural gas resources, and shale gas specifically, are essential to the energy security of the US and the world. Realization of the full benefit of this tremendous energy asset can only come about through resolution of controversies through effective policies and regulations. Fact-based regulation and policies based on sound science are essential for achieving the twin objectives of shale gas resource availability and protection of human health and the environment. The most rational path forward is to develop fact-based regulations of shale gas development based on what is currently known about the issues and, at the same time, continue research where needed for information to support controls in the future. Additional or improved controls must not only respond to the issues of controversy, but also address the full scope of shale gas development. Priorities must be set on the most important issues as well as on public perceptions. The path ahead must take advantage of the substantial body of policies and regulations already in place for conventional oil and gas operations. Enforcement of current and future regulations must also be ensured to meet the twin objectives of protection of the environment and other resources and gaining public acceptance and support.

Further information

Clarke, C., Boudet, H. & Bugden, D., 2012, *"Fracking" in the American Mind: Americans' Views on Natural Gas Drilling Using Hydraulic Fracturing*, George Mason University Center for Climate Change Communication and Yale Project on Climate Change Communication. Available at: http://climatechangecommunication.org/sites/default/files/reports/Fracking_In_the_American_Mind_2012.pdf

Ground Water Protection Council, 2009, *State Oil and Natural Gas Regulations Designed to Protect Water Resources*, US Department of Energy, National Energy Technology Laboratory. Available at: http://www.gwpc.org/sites/default/files/state_oil_and_gas_regulations_designed_to_protect_water_resources_0.pdf

Wang, Z. & Krupnick, A.J., 2013, *A Retrospective Review of Shale Gas Development in the United States: What Led to the Boom?* Resources for the Future, RFF Discussion Paper 13-12. Available at: http://www.rff.org/RFF/Documents/RFF-DP-13-12.pdf

Krupnick, A., Gordon, H. & Olmstead, S., 2013, *Pathways to Dialogue: What the Experts Say about the Environmental Risks of Shale Gas Development*, Resources for the Future, RFF Report. Available at: http://www.rff.org/Documents/RFF-Rpt-PathwaystoDialogue_FullReport.pdf

Resources For the Future, 2013, *A Review of Shale Gas Regulations by State, Center for Energy Economics and Policy*. Available at: http://www.rff.org/centers/energy_economics_and_policy/Pages/Shale_Maps.aspx

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