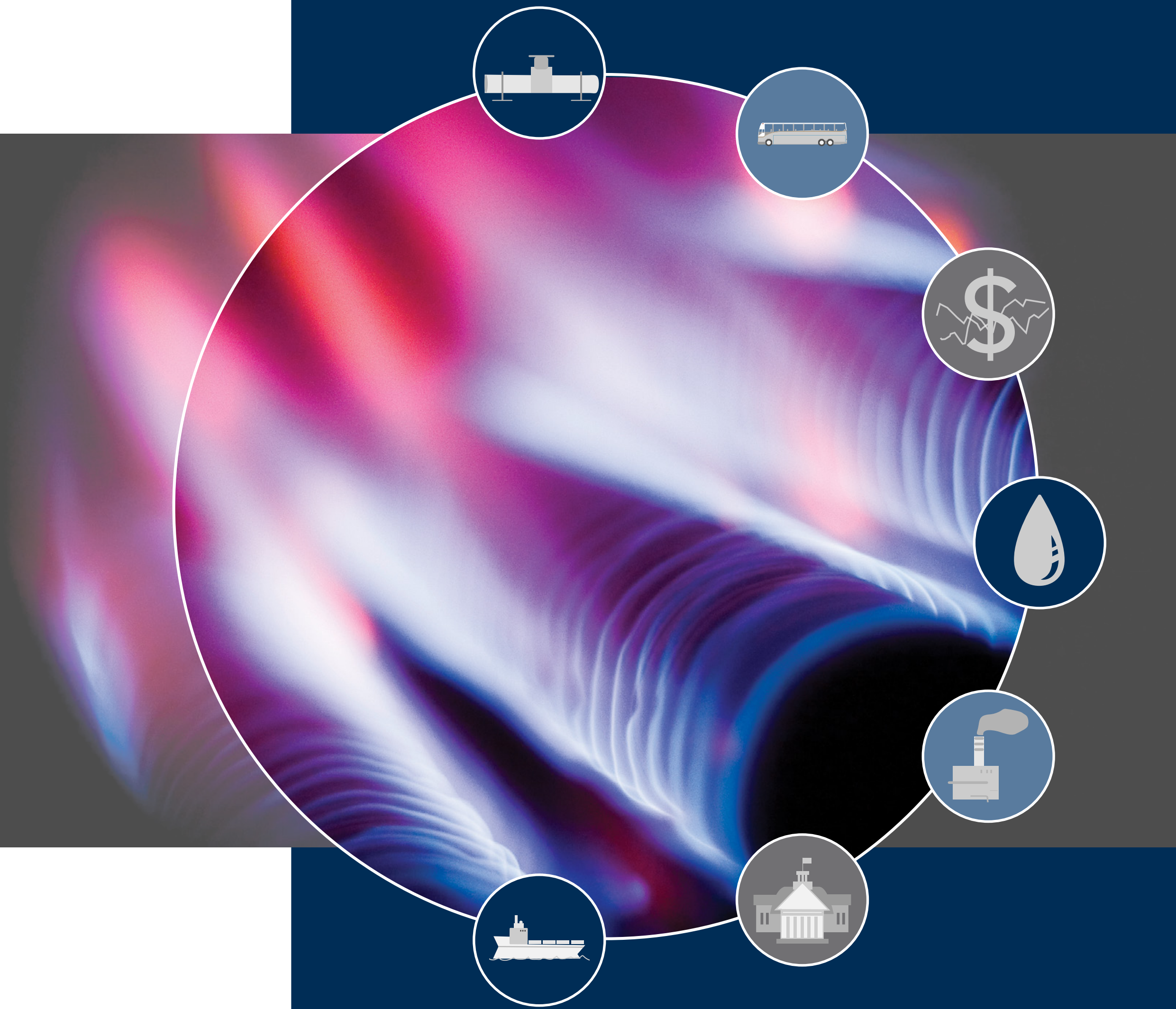
The Natural Gas Revolution:
Critical Questions for a Sustainable Energy Future



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About

This report is part of Resources for the Future's (RFF) Natural Gas Initiative, a collaboration between RFF's Center for Energy Economics and Policy (CEEP) and RFF's Center for Climate and Electricity Policy (CCEP).

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Resources for the Future (RFF) is an independent, nonpartisan organization that conducts economic research and analysis to help leaders make better decisions and craft smarter policies about natural resources and the environment. RFF is located in Washington, DC, and its research scope comprises programs in nations around the world.

Acronyms

AEO	Annual Energy Outlook
API	American Petroleum Institute
BAU	business as usual
BLM	US Bureau of Land Management
Btu	British thermal units
CCS	carbon capture and storage
CNG	compressed natural gas
DOI	US Department of the Interior
EDF	Environmental Defense Fund
EIA	US Energy Information Administration
EMF	Energy Modeling Forum
EPA	US Environmental Protection Agency
FEEM	Fondazione Eni Enrico Mattei
FTE	full time employee
GCAM	global change assessment model
GHG	greenhouse gas(es)
GDP	gross domestic product
IAM	integrated assessment model
IEA	International Energy Agency
INGAA	Interstate Natural Gas Association of America
JGCRI	Joint Global Change Research Institute
JKT	Japan, South Korea, and Taiwan
LNG	liquefied natural gas
mcf	million cubic feet
OECD	Organisation for Economic Co-operation and Development
PGC	Potential Gas Committee
ppm	parts per million
RPS	renewable portfolio standard
tcf	trillion cubic feet
TNC	The Nature Conservancy
USGS	US Geological Survey

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Introduction

Most experts agree that the ability to cost-effectively develop vast, globally dispersed deposits of natural gas is a game changer for the world's energy future. This resource base represents new opportunities for domestic and global economic growth, as well as changing fuel choice options in multiple sectors. However, conflicting studies, unavailable data, an evolving regulatory landscape, and public concern could hamper the potential for economic benefits and environmental improvements from natural gas.

It is time to take stock of what is known, what is uncertain, and what is unknown about the economic and environmental consequences of the natural gas revolution. The body of research and commentary is extensive, with many reports and articles pointing to ideas for further research. Few sources offer an overarching view of existing research, however, and even fewer studies attempt to draw conclusions about the adequacy of that research in answering critical questions. Here we aim to do just that.

In 2013, researchers at Resources for the Future (RFF) convened a group of nearly 60 experts from academia, federal and state governments, industry (including the financial sector), and nonprofits to discuss the state of knowledge related to shale gas markets, policy, and environmental risk. The group was asked to help identify "known unknowns," or what critical knowledge gaps remain.

We then conducted our own literature review, focusing primarily on socioeconomic research. We also identified some related areas of natural science and engineering where research seems to be needed. The results of this literature review—combined with outcomes from the convening of experts—are captured in this report.

We organized this report into seven areas related to the production and consumption of natural gas:

1. supply;
2. demand;
3. economic impacts;
4. environmental (and public health) impacts;
5. climate interactions and impacts;
6. regulation and other approaches to reduce risks; and
7. international implications.

Areas for further study are identified throughout the document, and some are called out as "Critical Questions"—resolving any of these questions would be fundamental to advancing the debate.

It is our hope that this information will inform the research efforts of those interested in ensuring long-term, sustainable natural gas development and foster ongoing dialogue and collaboration in service of that goal.

Critical Questions at a Glance

This report identifies 24 critical research questions in seven areas pertaining to the sustainable development of natural gas. Answering these questions would greatly enhance our knowledge of the domestic and global market for natural gas and the environmental implications of expanded gas extraction and use. This information would also be helpful for improving public policy on these issues.

There is a box around a question in each section—a short list of critical questions—for special attention. In our opinion, answering these questions would provide the highest value of information, increasing our knowledge by the greatest amount in each of the seven areas.

Moving forward, experts at RFF aim to undertake research in as many areas as possible, working with other researchers and knowledgeable stakeholders who are also seeking to reliably resolve many of these "known unknowns." By working together, we can help to identify how to best utilize natural gas for long-term economic and environmental sustainability.

The Expanding Supply of Natural Gas

Critical Question 1.

Substantial uncertainty exists about estimates of natural gas supply elasticity in the United States. This information is fundamental to understanding changes in gas prices in response to demand and other factors.

What are the price elasticities of supply (short, medium, and long term)? How sensitive are they to the continuing technological changes related to the development of shale gas? *(page 7)*

Critical Question 2.

Understanding the costs and benefits of regulation is critical to assessing the economics of future gas development in the United States.

What are the costs and benefits of existing and proposed regulations for shale gas development and how could those regulations shift the supply curve for natural gas? *(page 8)*

Critical Question 3.

Barriers to developing natural gas transmission and distribution infrastructure in the United States appear to be largely a matter of policy rather than markets. A comprehensive examination of regulatory frameworks will lay the groundwork for a more robust policy review.

How do existing regulatory frameworks affect the pace of infrastructure development, and what are the externalities associated with growing that network? *(page 8)*

Demand by Sector

Critical Question 4.

The forthcoming CO_2 regulations for existing power plants under the Clean Air Act could transform the electricity and energy sectors. Understanding the role that natural gas could play under these regulations will be critical to the nation's energy future.

How will regulation under the Clean Air Act affect natural gas use, coal use, and the deployment of renewables and nuclear? Will there be a need for new gas pipelines and electricity transmission infrastructure? *(page 10)*

Critical Question 5.

Global industrial demand for gas will likely grow in proportion to or at a slightly greater rate than economic activity, due to the availability of abundant natural gas as an industrial feedstock. However, the global distribution of this growth could be quite uneven due to disparities in global gas prices.

How much would the continued availability of inexpensive domestic gas increase the global competitiveness of US industrial feedstock-related products? Does potential exist for significant industrial self-generation of electricity using natural gas? *(page 11)*

Economic Consequences of Increased Natural Gas Production

Critical Question 6.

Sharing state revenues (for example, through severance taxes or impact fees) with local governments can be important for compensating local communities for the negative impacts of shale gas development.

How do these processes compare across states and what improvements can be made? *(page 15)*

Critical Question 7.

Shale gas regulations should be informed by an in-depth cost–benefit analysis of various regions that have experienced the migration of businesses and people related to shale gas development.

What are the net benefits of shale gas development to local communities and how can they be maximized? *(page 16)*

Critical Question 8.

Relatively few studies address the downstream economic impacts of the shale gas revolution on gas-using industries, but there is significant interest from the public and private sectors in understanding these impacts.

How will the shale gas revolution affect employment, output, and investment activities for industries that are likely to benefit from lower natural gas prices (such as aluminum, cement, iron and steel, glass, paper, rubber, and plastics)? *(page 17)*

Environmental Impacts

Critical Question 9.

Risks to surface water quality and quantity associated with shale gas development are a major concern of communities and operators alike.

How great are the risks to surface water quality and quantity? How effective are the various techniques and policies for mitigating such risks (in general and specifically in water-scarce areas)? *(page 19)*

Critical Question 10.

The public is concerned about potential groundwater pollution from shale gas development. Industry could release data related to well integrity and from before and after testing of drinking water to shed light on these issues.

What is the magnitude and frequency of groundwater impacts from shale gas development, according to industry testing data (and other sources of data)? *(page 20)*

Critical Question 11.

The impact of shale gas development activities on wildlife habitats is still unclear. Such information would be very valuable in identifying "optimal" siting for development.

How severe is habitat fragmentation as a result of shale gas development? How can impacts on habitat and biodiversity be reduced? *(page 20)*

Critical Question 12.

The public is concerned about potential health effects from shale gas development, yet there are few studies that adequately demonstrate the impacts.

How has public health (both mental and physical) been affected by shale gas development? What potential future impacts exist? And how could such impacts be reduced through policy? *(page 21)*

Critical Question 13.

Understanding the public's willingness to pay for risk reductions is key for estimating the benefits of risk mitigation activities. This requires the use of stated and revealed preference approaches.

How much is the public willing to pay to reduce risks associated with shale gas development? *(page 22)*

Critical Question 14.

The erosion of public trust in institutions is a major roadblock to sustainable shale gas development.

How can public trust in institutions, both government and the oil and gas industry, be enhanced? *(page 23)*

Abundant Gas and Global Climate Protection

Critical Question 15.

The role of natural gas in reducing global CO_2 emissions is unclear. Understanding this is crucial for countries such as China and India, where rapid growth in electricity (and natural gas) demand is expected.

How will current levels of CO_2 emissions be affected when natural gas substitutes for coal and nuclear power in electricity generation? How will these substitutions affect renewables penetration in the short and long term? How much will demand for electricity increase because of lower natural gas prices? *(page 25)*

Critical Question 16.

More studies on fugitive methane emissions are required to build a consensus on their magnitude relative to the greenhouse gas (GHG) emissions from coal combustion in the United States and elsewhere.

How will expanding gas extraction activities in Russia, the United States, and other major current and future gas suppliers affect global GHG emissions levels? *(page 26)*

Critical Question 17.

Recent global modeling of aggressive GHG mitigation policies suggests that large-scale natural gas use will require carbon capture and storage (CCS) early in the century to support such policies; however, such aggressive goals require equally aggressive government policies.

Looking at the top GHG emitting nations, what role can be played in the early part of century by gas without CCS and what relaxed emissions reductions goals are consistent with that gas use? *(page 27)*

Regulation, Best Practice, and Liability

Critical Question 18.

Shale gas development has grown very quickly, often leaving states to "catch up" in determining the best approaches for regulating such activity.

How can state regulation of shale gas development—including monitoring and enforcement, and the regulations themselves—be improved? How can they be more cost-effective? *(page 29)*

Critical Question 19.

Debate continues about which levels of government should have the authority and responsibility to regulate shale gas development. Informing this debate will require both empirical and applied research from various disciplines including law, political economy, and economics.

What aspects of shale gas development can and should be regulated at the federal, state, and local levels, and can such an approach be applied across states? *(page 30)*

Critical Question 20.

At least 20 guidance documents for industry best practices have been produced by a variety of stakeholders—but there are no studies that compare these guidelines or take the next step of comparing those findings to regulations.

What is the appropriate role for best practice guidelines (voluntary behavior by industry) versus government regulation? *(page 31)*

Critical Question 21.

Discussions about improving shale gas development often refer to developing more and better regulations and/or encouraging such behavior through voluntary industry activities (best practices). However, holding companies liable for their actions (the liability system) is the often-ignored third leg for improving industry practice.

In considering regulation, best practices, and liability, what are the strengths and weaknesses (including cost-effectiveness) of the three approaches? Under what circumstances are these approaches substitutes or complements? *(page 31)*

International Markets for Natural Gas

Critical Question 22.

Integrated electricity and environmental modeling used in the United States and Europe helps decisionmakers better understand how lower natural gas (and oil) prices and policy drivers impact regional demand. However, such modeling is not widespread in other countries.

Using such models, how will lower natural gas prices and policy drivers affect regional demand in countries such as China, India, and other Asian nations? *(page 32)*

Critical Question 23.

The development and expansion of the global LNG market will depend on the regional patterns of demand, new sources of supply, and the evolution of pipelines and other infrastructure.

Which countries are potential suppliers and demanders of natural gas in the international market? What barriers exist (regulatory, infrastructure, and so on) for the sustainable deployment of natural gas in trade, and how can those barriers be removed? *(page 33)*

Critical Question 24.

Given the large capital investment required to export LNG, expanding the market requires pricing and other contractual arrangements between the buyer and seller that reduce investment risk. At present, pricing mechanisms and contract provisions are evolving in response to new demand and supply conditions.

How important will the very short-term contract spot market be over the next decade? Will hub pricing be established in the Asia Pacific region? If so, when and where, and what will drive its establishment? What forms will long-term contracts take over the next decade? *(page 34)*

The Expanding Supply of Natural Gas

Various organizations and government agencies report on the domestic and international natural gas resource base using different methodologies and terminologies, making comparisons challenging.[1] Nonetheless, all estimates released in the past few years indicate that the United States (and the world) has a large resource base of gas in shale, which will result in a substantial supply of natural gas available. This section begins by looking at issues related to that supply, including the following:

- the current understanding of the domestic and international resource base;
- research on elasticity of supply (how much gas would be brought to the market at any given price, and how quickly gas would be supplied to or withdrawn from the market in response to a price change);
- how changing costs of production and/or regulation might affect supply; and
- how infrastructure constraints or developments might impact supply.

Resource Base

The US Energy Information Administration (EIA) recently released its latest figures on the domestic natural gas resource base, with data through the end of 2011. It shows total US dry gas proved reserves[2] of 334 trillion cubic feet (tcf) in 2011 (EIA 2013c), the highest number reported since recordkeeping began in 1925. Of this, about 132 tcf are estimated to be shale gas resources, all located in the lower 48 states (EIA 2013d).

Proved reserves are only one measure of the natural gas resource base; another frequently used metric is technically recoverable resources, a broader measure defined by EIA (2012, 124) as "resources in accumulations producible using current recovery technology but without reference to economic profitability." Between 2010 and 2011, EIA more than doubled its estimates of US technically recoverable shale gas resources from 347 to 827 tcf. This estimate has since been revised down to 665 tcf (EIA 2013e), although Advanced Resources International suggests in its 2013 projections (joint with EIA) that the United States may have more than 1,100 tcf of technically recoverable shale gas resources (EIA 2013e).

Combined with its estimates of non–shale gas resources, EIA estimates that the United States has 2,431 tcf of technically recoverable natural gas resources overall (EIA 2013e). This aligns closely with estimates from the Potential Gas Committee (PGC), which, in April 2013, reported a total technically recoverable resource base in the United States of 2,384 tcf (PGC 2013).

Predictions of the international shale gas resource base are more uncertain, where geology is less tested and production costs are less understood. EIA and Advanced Resources International also evaluated these resources, releasing an initial assessment in April 2011 and an update in June 2013. Even over that short time frame, their estimates of global shale gas resource potential (most

[1] For a detailed discussion of some of the challenges in terminology, see IPAA (n.d.), "Oil and Natural Gas Reserves—Definitions Matter."

[2] The US Energy Information Administration (EIA) defines proved energy reserves as "[e]stimated quantities of energy sources that analysis of geologic and engineering data demonstrates with reasonable certainty are recoverable under existing economic and operating conditions. The location, quantity, and grade of the energy source are usually considered to be well established in such reserves" (EIA n.d.-a).

closely correlated to technically recoverable resources) rose by 10 percent, from 6,622 tcf to 7,299 tcf (EIA 2013f). In order, the top 10 countries with technically recoverable shale gas resources are China, Argentina, Algeria, the United States, Canada, Mexico, Australia, South Africa, Russia, and Brazil. Other estimates of the global resource base are included in the Massachusetts Institute of Technology's The Future of Natural Gas study (MIT Energy Initiative 2011) and the series of World Energy Outlooks produced by the International Energy Agency (IEA).

More research to refine estimates of technically recoverable and proved resources would help international governments and companies seeking to tap into new plays. This issue is of less priority for the United States, where ongoing questions of production and regulatory cost uncertainty are arguably of greater importance (and are described in more detail below).

Supply Elasticities

Beyond understanding how much natural gas is available at current prices at any point, it is critical to understand how much gas will be produced at alternative prices—in other words, the supply curve for natural gas. With this curve, we can estimate how responsive the quantity supplied is to changes in price—the price elasticity of supply. Economists estimate these elasticities over the short, medium, and long term, with greater elasticity expected over longer time frames because companies have more time to adjust to price signals.

Beyond such estimates in existing models, several groups of researchers are undertaking work to develop improved supply curves and, from these, their implied elasticities. For example, Kenneth Medlock at Rice University derived price elasticities of supply from the Rice World Gas Trade Model, finding that the domestic supply curve is much more elastic given the expansion of shale gas supplies (as would be expected). He notes a domestic long-run elasticity of only 0.29 without newly available shale gas, but a significantly greater elasticity (1.52) with shale gas (Medlock 2012).

Another key effort in this area comes from the Energy Modeling Forum 26 (EMF26), led by Hillard Huntington at Stanford University. Modeling results from the EMF26 report released in September 2013 (EMF 2013) show a wide spectrum of supply elasticities, ranging from a relatively weak supply response to price (an implied price elasticity of supply of 0.5 or less) to quite strong supply responses (with an implied elasticity of 2 or more). However, researchers involved with EMF are careful to note that this range reflects differing model assumptions and different methods for calculating elasticities—some of which are actually endogenous to the models themselves. Rather than pointing to any definitive answer on supply elasticity, the report notes the continuing uncertainties in this area and the difficulty of making apples-to-apples comparisons.

In considering the Barnett shale play in Texas, a team at the University of Texas's Bureau of Economic Geology (Browning, Ikonnikova, et al. 2013; Browning, Tinker, et al. 2013) estimates that, based on a gas price of $4 per million cubic feet (mcf) at Henry Hub (the primary market for natural gas in the United States and a point where major pipelines come together), remaining production would be 2.5 times that of cumulative production to date. Although no supply elasticities are explicitly reported, the supply appears surprisingly inelastic: moving the price from $3 per million British thermal units (Btu) to $4 increases cumulative production about 3 percent by 2030, for an elasticity of 0.10. Increasing the price from $4 to $6 per million Btu raises production by around 7 percent, for an elasticity of 0.14. However, this elasticity is probably low because the Barnett play is mature; elasticities are likely to be far larger for the Marcellus and other less well-developed plays.

Critical Question 1.

Substantial uncertainty exists about estimates of natural gas supply elasticity in the United States. This information is fundamental to understanding changes in gas prices in response to demand and other factors.

What are the price elasticities of supply (short, medium, and long term)? How sensitive are they to the continuing technological changes related to the development of shale gas?

Production Cost Uncertainty

The supply curve itself can be unpacked into production costs per unit of gas produced (which have above ground and below ground elements, the latter depending critically on geology), regulatory costs, financing costs, the desired rate of return, and a host of other factors. The two elements discussed most at the RFF expert workshop were production costs and regulatory costs. Production costs, which can vary widely from play to play (and even well to well), are notoriously hard to identify. Even small changes in these production costs can affect a well's economic viability and, therefore, supply estimates.

Notably, some of these costs are calculated on a per-well basis (drilling, fracturing, and completion), whereas others may be calculated on a per-pad or per-parcel basis—and given that the number of wells per pad or per parcel can vary, per-well calculations are very challenging. Negotiations with landowners can also result in radically varying costs of acquisition and leasing. Although information of this depth and detail is available within the industry and included in certain models, it is largely lacking in the public domain, making future modeling challenging. Exploration and production cost data are even harder to come by in an international context. Can production cost uncertainties be resolved? If so, how? Or, at the very least, how can this information be made more public?

Similarly, debate over the potential costs of proposed regulatory measures is considerable—particularly given the concerns that local bans and moratoria or tight regulation will raise compliance costs to a point that strongly curtails production.

Some research relies on production cost models. For instance, IHS (2013) models a low production case, in which unspecified but significant new regulatory frameworks lead to heightened costs. They find that the estimated increased restrictions on drilling and costs of compliance result in a 67 percent reduction in unconventional gas drilling activity through 2035. This low production case arguably represents an extreme instance of newly imposed regulatory frameworks, however, and does not examine any individual policy proposals.

In general, where individual regulatory proposals have been made, little is known about their impact on driller costs or decisions (or conclusions are highly contradictory). The Natural Resources Defense Council illustrates this, with commentary on competing estimates of the regulatory measure proposed by the US Environmental Protection Agency (EPA) on "green completions" for shale gas development (Gowrishankar 2012). The author notes an EPA estimate of $170 million in upfront industry-wide investments to comply with the regulation. At the same time, the author writes that "in November 2011, the American Petroleum Institute (API) claimed sky-high annual costs of compliance, with an estimate of more than $2.5 billion. . . . In comparison, a [Bloomberg Government] report estimates a net cost between $300 and $500 million" (Gowrishankar 2012). Underpinning these discrepancies are very different assumptions about production cost.

One frequently noted estimate of regulatory costs comes from IEA's (2012) Golden Rules for a Golden Age of Gas report, which notes that if producers adhere to seven "golden rules" for addressing the environmental and social impacts of gas development, the costs of a typical shale gas well will rise by around 7 percent. IEA had to make many assumptions to arrive at this figure, however, and doesn't specify whether behaviors in line with these rules would be driven by regulation or best practice.

Critical Question 2.

Understanding the costs and benefits of regulation is critical to assessing the economics of future gas development in the United States.

What are the costs and benefits of existing and proposed regulations for shale gas development and how could those regulations shift the supply curve for natural gas?

Infrastructure

A critical component of getting produced gas to market is sufficient infrastructure, including gas processing, storage, and compression facilities, as well as a network of pipelines robust enough to transport the gas from the production site. The United States has more existing natural gas interstate and intrastate transmission pipelines than any other nation in the world, although the Interstate Natural Gas Association of America (INGAA) estimates that more than $205 billion in new capital requirements will be needed over the next 25 years (INGAA 2011). This includes estimates for storage fields, processing plants, various types of pipelines (main, lateral, and gathering), and compression.

A relatively settled question is where the funding for this expanded infrastructure will come from. The INGAA report notes that "[h]istorically, the industry has proven its ability to finance and construct this level of infrastructure. Industry investments in pipeline infrastructure alone equaled or exceeded $8 billion per year in three of the past four years" (INGAA 2011).

Critical Question 3.

Barriers to developing natural gas transmission and distribution infrastructure in the United States appear to be largely a matter of policy rather than markets. A comprehensive examination of regulatory frameworks will lay the groundwork for a more robust policy review.

How do existing regulatory frameworks affect the pace of infrastructure development, and what are the externalities associated with growing that network?

Demand by Sector

EIA reports (EIA n.d.-c) that total annual US natural gas consumption rose by over 3.8 tcf from 2006 to 2012, almost 18 percent—illustrating a clear and growing place for natural gas in the US economy. To address future drivers of natural gas demand in the United States, this section covers the following:

- expectations for the role of natural gas in power generation;
- the influence of increased domestic gas availability and lower gas prices on the manufacturing and industrial sectors;
- the role gas has played and might play as a transportation fuel; and
- the future of US gas exports via pipeline or as liquefied natural gas (LNG).

Figure 1, generated with 2013 data from EIA, illustrates the consumption of natural gas by sector. Since 2004 or so, electric power generation and industrial use have been the two largest sources of natural gas demand—and this trend is expected to continue over the next several decades.

Recent work from Stanford's EMF26 (EMF 2013) suggests relative agreement across a number of models with respect to aggregate US natural gas demand, but disparity across the models with respect to sectoral demand—especially in the case of the industrial and electricity sectors.

The Electric Power Sector

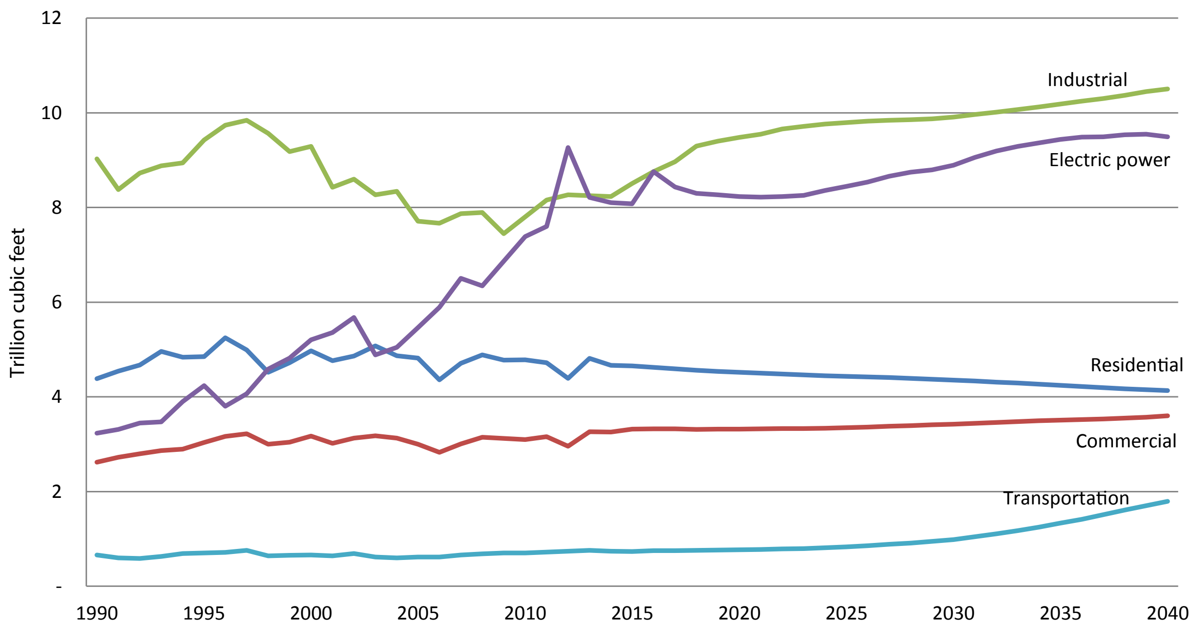
From 2002 to 2012, according to EIA's *Annual Energy Outlook 2013* (AEO2013), natural gas demand for power generation rose more than 60 percent, or about 3.5 tcf (EIA 2013a), and this growth in demand is projected to continue. At the same time, the AEO2013 assumes that all existing policies remain in place over the forecast period and does not include any new policy.

In particular, the AEO2013 does not include future regulations of carbon dioxide (CO_2) under provisions of the Clean Air Act for new and existing plants, even though those regulations are being promulgated today. Because these regulations can, and probably will, impact the future generation mix of utilities and demand for natural gas, a basic understanding of the interplay between future CO_2 regulations, generation mix, impacts on electricity price, and the demand for gas is crucial.

One can gain an approximation of the effect of CO_2 regulations on the electric power sector demand for natural gas by modeling a tax on power sector CO_2 emissions. Because coal produces more CO_2 than natural gas per unit of energy, the impact of a tax on CO_2 would accelerate the penetration of gas as a substitute for coal.[3] RFF performed a CO_2 tax modeling analysis (Paul, Beasley, and Palmer 2013) using the RFF HAIKU model, setting tax rates equal to the revised social cost of carbon estimates released by the White House in 2013 (IWG 2013). In a scenario where the tax equals the middle of a range of estimates of the social cost of carbon ($38 per ton in 2010, escalating to $65 by 2035), gas demand is 70 percent greater than the baseline in 2035.

[3] Since hydro, nuclear, and renewables are carbon free, the CO_2 tax could accelerate the deployment of these technologies as well (depending, of course, on their relative fixed and variable costs). A tax on greenhouse gas emissions, on the other hand, would only advantage gas over coal if fugitive emissions are low.

Figure 1. Natural Gas Consumption by Sector, 1990–2040 (trillion cubic feet)



Source: EIA 2013b.

Of course, EPA regulation of CO_2 emissions under the Clean Air Act will not take the form of a federal carbon tax. The stringency of the regulations EPA does promulgate is unknown at present and may not be the theoretically desirable stringency (that is, where marginal control costs equal the social cost of carbon). However, the social cost of carbon was developed for rulemaking purposes, and could be used as one input to a regulatory process setting the stringency of forthcoming CO_2 regulations.

Critical Question 4.

The forthcoming CO_2 regulations for existing power plants under the Clean Air Act could transform the electricity and energy sectors. Understanding the role that natural gas could play under these regulations will be critical to the nation's energy future.

How will regulation under the Clean Air Act affect natural gas use, coal use, and the deployment of renewables and nuclear? Will there be a need for new gas pipelines and electricity transmission infrastructure?

The Industrial Sector

Until recently, the industrial sector consumed more natural gas than any other sector in the United States and, according to AEO2013 estimates, is expected to retake the lead in the next few years. Industrial demand is driven largely by price, as evidenced by the decline in demand over the 2000–2010 period of high gas prices and the EIA-forecast return of demand to pre-2000 levels by 2020 due to significantly lower prices.

Industrial customers use natural gas in a variety of ways. These include direct or process heating, in firing boilers to generate steam, and in operating combined heat and power systems to provide both steam and electricity from a single gas-fired unit. Natural gas and natural gas liquids are also used as feedstock in the manufacturing of ammonia, fertilizers, and numerous other chemicals.

Using data from EIA's 2010 Manufacturing Energy Consumption Survey, the Center for Climate and Energy Solutions (2012) looked at how gas use is distributed across industrial operations. It shows that the vast majority of natural gas is used in process heating and boiler firing, whereas feedstock uses constitute only 7 percent of overall industrial use—even though feedstock use has arguably received the most attention in recent policy and research discussions.

One can imagine expected future US gas prices stimulating growth in all of these areas due to increased economic activity. One can also imagine international commodity companies (such as producers of fertilizer and industrial chemicals) that are heavy users of natural gas for feedstock purposes continuing to move to the United States for more competitive prices. For these reasons, natural gas demand in the industrial sector may be expected to grow at a small rate above growth in domestic industrial activity.

Technological innovation within electric power generation could lead to an increase in industrial demand for gas above the demand driven by growth in general economic activity. As technical progress lowers the cost of on-site generation (distributed generation) and costs rise within the traditional central power–oriented electric utilities, industrial customers may find it to their advantage to self-generate through one of the new gas-powered technologies. This may not increase overall, economy-wide gas demand, but it might shift demand from the utility sector to the industrial sector.

Critical Question 5.

Global industrial demand for gas will likely grow in proportion to or at a slightly greater rate than economic activity, due to the availability of abundant natural gas as an industrial feedstock. However, the global distribution of this growth could be quite uneven due to disparities in global gas prices.

How much would the continued availability of inexpensive domestic gas increase the global competitiveness of US industrial feedstock-related products? Does potential exist for significant industrial self-generation of electricity using natural gas?

The Transportation Sector

Direct Use in Vehicles

Currently, most light-duty and medium-duty natural gas vehicles in the United States run on compressed natural gas (CNG), whereas the largest, heavy-duty vehicles run on LNG; in all vehicle classes (except refuse trucks), however, penetration of natural gas vehicles remains very low. The reasons for this low penetration rate are relatively well discussed, particularly the "chicken-and-egg" relationship between vehicle demand and development of refueling infrastructure. Natural gas vehicles have been adopted more quickly by fleets and in other situations where vehicles refuel at set locations, but adoption in the broader passenger vehicle market has been limited because of the small number of publicly available refueling stations.

Nonetheless, many reports (and some purchasing and infrastructure development decisions) indicate optimism about a growing role for natural gas in fueling heavy-duty vehicles. Analysis by RFF researchers (and others) suggests that LNG trucks can, under certain conditions, have attractive payback periods even without government subsidies—and that infrastructure issues may be less challenging than commonly thought because some companies are already investing in refueling infrastructure and because the trucking sector is moving away from the long-haul model to a hub-and-spoke model, whereby fewer stations are needed (Krupnick 2011). Demand for LNG for rail and barge transport is also growing.

In the near term, the United States is unlikely to invest in refueling infrastructure widespread enough to encourage large-scale adoption of CNG light-duty vehicles. At the same time, niche vehicles and fleet vehicles will probably continue to be fueled by CNG, and a growing number of domestic carmakers have announced production of natural gas vehicles or bi-fuel vehicles that can run on either natural gas or gasoline. The National Renewable Energy Laboratory suggests that "[b]i-fuel gasoline–natural gas vehicles may serve as a bridge technology to ease consumer adoption issues, encourage refueling infrastructure build out, and facilitate a larger penetration of light-duty [natural gas vehicles]" (Lee, Zinaman, and Logan 2012).

The public's demand for natural gas vehicles is largely unknown. Following the literature estimating the demand for other alternative-fueled vehicles, research could explore the public's willingness to pay for a range of environmental, fuel economy, and energy security attributes associated with natural gas vehicles.

Conversion to Other Liquid Fuels

More interesting questions arise when considering how natural gas might be used as a feedstock to produce other liquid fuels, including ethanol, methanol, diesel, and even gasoline. For example, Celanese Corporation and Coskata, Inc., have both developed processes for producing ethanol from natural gas (Bromberg and Cheng 2010; Coskata n.d.). An RFF research team compared the economics of running light-duty vehicles on gas-derived ethanol versus traditional gasoline, estimating that drivers who drive 15,000 miles per year could benefit from fuel cost savings between $157 and $439 per year (Fraas, Harrington, and Morgenstern 2013). Ethanol is attractive because millions of vehicles already have the capability to use E85 (a fuel blend comprised of 85 percent ethanol and 15 percent gasoline or other hydrocarbon by volume) without needing any power train conversions. E85 is already transported by rail, barge, and truck, but pipeline transport would require separate pipeline infrastructure.

As for the other fuels, natural gas to diesel and gasoline are obviously the most attractive in terms of infrastructure and power trains because no additional investments are required. Natural gas to diesel is particularly attractive if fuel prices can be dropped below those of crude-derived diesel because commercial users (such as trucks, locomotives, and ships) travel so many miles. However, the economic viability of any gas-to-liquid fuel conversion depends on the price spread between gas and oil and the certainty that spread will remain economic over the life of the capital investments. At present there is a great deal of uncertainty with respect to the size and intertemporal stability of that spread.

Given the development of gas-to-liquid technologies and expectations (albeit uncertain) of continued low natural gas prices and crude prices around $100 per barrel, research is warranted on the capital and operating costs of large-scale deployment of these technologies, and of the demand and environmental implications of these fuels.

Exports

Although US LNG exports are currently trivially small, US exports of gas via pipelines totaled about 1.6 tcf in 2012, up 350 percent in the last decade (EIA n.d.-d). US export potential is driven by international demand, but also by the domestic price in the export market and the delivered price of gas from the United States to the export market.

BP reported natural gas prices for selected global markets for 2012: Japan LNG at US$16.75 per million Btu,[4] German imported natural gas at US$11.03 per million Btu, UK gas at US$9.46, and US Henry Hub price at US$2.76 (BP 2013). In the last half of 2013 the Henry Hub price averaged $3.67 (EIA n.d.-b). Using the later 2013 Henry Hub price and assuming rough estimates of liquefaction costs at $2 per million Btu and transportation at another $2 suggests a delivered price in the $8 range. At that price, a good deal of headroom exists for US LNG exports into the Japanese market, but smaller spreads in the EU and UK markets.

Competition from other international or domestic suppliers and rising gas prices in the United States can dampen the growth of US exports—and even if global and domestic gas prices are conducive to a sizable US-based export market, the infrastructure required may be a limiting factor. Although planned and permitted LNG import facilities may be reconfigured for export, investments are still large (perhaps in the $6–$7 billion range). Regulations or simple construction problems can delay the completion of these facilities and thereby participation in the global LNG market. Moreover, greenfield facilities will have considerably more regulatory hurdles to clear and will require greater investment, making them financially sensitive to delays.

New LNG export facilities have very large capital requirements and those capital costs are rising. Deutsche Bank research estimates that the capital expenditure, or capex, for new facilities is $2.6 billion per million metric tonnes per annum, noting that this figure is more than double the historic average (EY2013). Opposition to these facilities, for both "not in my backyard" reasons and broader environmental concerns, can delay or derail licensing, permitting, and construction, causing costs to rise further.[5] Attractive prevailing prices in markets such as Japan, South Korea, and Taiwan (JKT) have the eye of other potential exporters as well as the United States, and emerging markets, including China and India, could be a great deal more price sensitive than JKT. Uncertainty with respect to rising capital costs, export facility opposition, and characteristics of the demand markets makes long-term forecasting and planning for the US LNG export market a difficult undertaking.

[4] Less optimistic estimates of Gulf Coast–delivered LNG to Japan are in the $10 per million Btu range (EY 2013).

[5] See, for example, Wheeler 2013.

Economic Consequences of Increased Natural Gas Production

The shale gas revolution has already led to economic benefits (and costs) at the state and local levels, to individual sectors, and to the nation. This section examines the literature on impacts to gross domestic product (GDP), jobs, and other metrics.

Local Economic Impacts

Numerous studies have addressed the local, regional, or state economic impacts of shale gas production, including providing estimates of revenue generated, jobs created, and regional product changes. A few also address property value changes, local sectoral impacts (such as tourism and crime), and the boom-and-bust cycle. Several of these reports are qualitative in nature; the Bipartisan Policy Center (BPC 2012), for example, lists the benefits, including the diverse end uses of natural gas, and how those would translate into broader economic benefits.

Economic Growth Indicators

Much controversy has surrounded the actual size of local economic benefits. An example concerns a series of studies on impacts in the Marcellus play (Considine, Watson, and Blumsack 2011; Considine 2010; Considine, Watson, and Blumsack 2010) in New York, Pennsylvania, and West Virginia, based on the IMPLAN input–output model. One of these studies, sponsored by the Marcellus Shale Coalition, attributes 44,000 new jobs to shale gas development in Pennsylvania and \$3.9 billion in value added, with tax revenues increased by \$398 million, all in 2009 (Considine, Watson, and Blumsack 2010).

Kelsey (2011), using the same model but supplementing it with surveys of businesses, landowners, and local government officials as well as a GIS analysis of landownership, finds gains of only 24,000 new jobs and \$3 billion of value-added revenues in Pennsylvania during 2009. Kelsey (2011) attributes these lower economic gains to considering the associated leakage of benefits outside the state.

Two reports address the potential and hypothetical economic impacts in New York if the state were to lift the current moratorium on horizontal drilling. Though the job estimates in the two reports are somewhat similar, the conclusions are different. Considine et al. Considine, Watson, and Considine (2011) estimate that between 15,000 and 18,000 jobs could be created by allowing drilling in the Marcellus shale, and an additional 75,000 to 90,000 new jobs if drilling in the Utica shale commences. They conclude that this would cause large economic outputs in the state and large increases in tax revenues. Similarly, a report conducted for the New York State Department of Environmental Conservation concludes that natural gas operations would produce between 12,491 and 90,510 direct and indirect jobs. However, this report implies that these additional jobs are not very significant because they account for only between 0.1 and 0.8 percent of New York State's 2010 total labor force (Ecology and Environment 2011).

Using drilling and employment data from the Marcellus shale, Brundage et al. (2011) examine the jobs benefits in some detail. They find that bringing one Marcellus well online requires an average of about 420 individuals across 150 occupations, doing the equivalent work of about 13 full time employees (FTEs) per year. During the early years of development, most workers were hired from out of state. By 2011, 65 to 75 percent of new Marcellus workers were Pennsylvania residents (Brundage et al. 2011). Of all jobs, 70 to 80 percent are low-skilled or semi-skilled.

Demand for state-level estimates of economic benefits from shale gas development is significant. At the same time, such studies usually would not capture out-of-state leakages, which are an important component of a complete benefits (and costs) picture. Thus, economic benefits studies at this level do not seem as relevant as those at the national level, which capture these leakage effects.

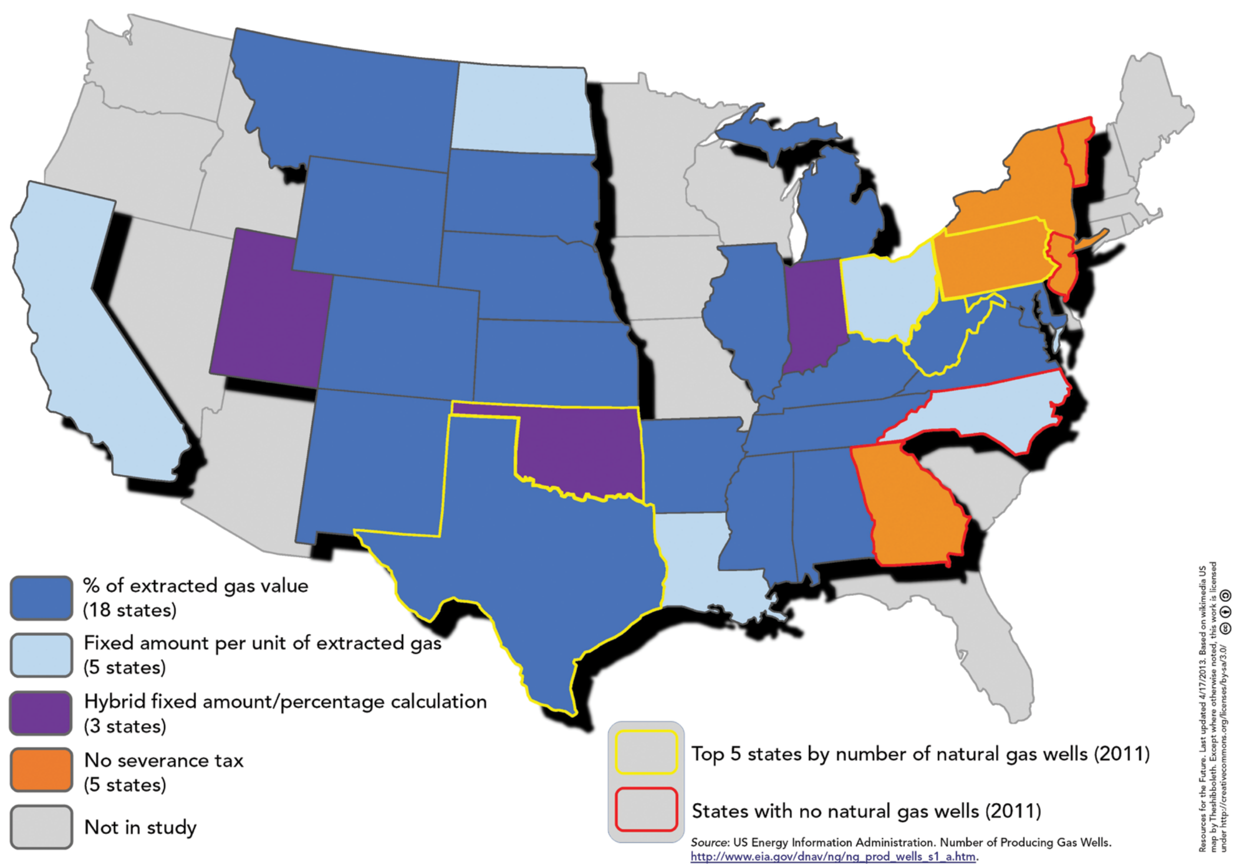
What is unassailable is that state revenues are up due to payments of severance taxes. Richardson et al. (2013) show how these severance tax rates vary by state and that two different formulas are used—one is a tax amount per unit of gas extracted and the other is a percentage of the value of gas extracted (see Figure 2).

According to US Census data, total severance tax state revenue was $13.4 billion in 2009 (almost 2 percent of total state tax revenue). In a comparison of state severance tax rates, Ozpehriz (2010) finds that, as expected, for states with more gas production and higher tax rates, a natural gas severance tax accounted for a higher percentage of their total state tax revenue. Alaska severance taxes made up 77 percent of the state's revenues in 2009, whereas the next top states were Wyoming (43 percent) and North Dakota (34 percent).

Rather than imposing a severance tax on the amount of gas extracted, Pennsylvania levies an impact fee on every producing oil and gas well in the state once a year. The fee varies based on the annual average natural gas price and on the number of years since the well spud. Pennsylvania is the only gas-producing state that imposes this kind of fee. In 2012, drillers paid a drilling fee of $50,000 per well (PBPC 2012). In an analysis, the Pennsylvania Budget and Policy Center (2013) estimates that the impact fee will generate between $237 million and $261 million in revenues by 2015, compared to an estimated $800 million if the state imposed a 5 percent severance tax on the production value of the gas.

In a recent analysis of severance tax revenues, the National Conference of State Legislatures found that most states allocate a portion of their revenues to the state's general fund or toward oil and gas development and regulation. Fewer states allocate their funds to local governments and school- and transportation-related purposes (Brown 2013). Information on Pennsylvania's impact fee system (Pifer 2013) indicates that local governments receive only about 47 percent of the revenues collected; given the structure of this system, these local distributions may have little or no relationship to local impacts.

Figure 2. Severance Tax Calculation Method



Source: Richardson et al. 2013.

Critical Question 6.

Sharing state revenues (for example, through severance taxes or impact fees) with local governments can be important for compensating local communities for the negative impacts of shale gas development.

How do these processes compare across states and what improvements can be made?

Retail Activity

Little information is available on how shale gas development has affected local retail activity. Costanza and Kelsey (2012) use sales tax collections as a means of understanding the level of retail activity occurring at the county level. They find a positive relationship between sales and shale gas activity in Pennsylvania. Though the results displayed considerable variation (Bradford at 50.8 percent, Greene at 31.4 percent, and Susquehanna at 27.4 percent), these counties all experienced large increases in retail sales activity in 2011.

Property Values

Two similar and broadly reinforcing studies have examined the property value impacts of shale gas development, both in Washington County, Pennsylvania. Gopalakrishnan and Klaiber (2014) find that, generally, property values decreased with development, but these decreases were largely transitory and depend on the proximity and intensity of shale gas activity. They also find that the impacts are heterogeneous and that negative effects disproportionately fall on "households that rely on well water, are located close to major highways, or are located in more agricultural areas" (Gopalakrishnan and Klaiber 2014, 44).

Muehlenbachs et al. (2013) also analyze property values in Pennsylvania and New York, from January 1995 to April 2012 at various distances from drilling sites. They find that homes located near shale gas wells experienced an increase in property value if they had access to piped water compared to similar homes farther away, whereas groundwater-dependent homes that were in close proximity (0.63 to 0.93 miles) to a natural gas well experienced a 10 to 22 percent decrease in value compared to similar homes farther away. Overall, then, negative perceptions of environmental risks to groundwater caused close-in housing prices to drop. From a broader municipal and county perspective, Kelsey, Adams, and Milchak (2012) find that shale gas development had minor impacts on the real property tax base.

Research on property value impacts in other areas of the country is warranted, particularly in areas with a longer history of oil and gas extraction (such as Texas), considering changes in techniques and risks over time. Even though they are a fairly narrow impact measure, property values integrate public sentiments about risks and benefits and are behaviorally based—in other words, they depend on actual buying and selling behavior.

Other Impacts

Many critics of studies showing positive economic effects at the local and state levels say that such studies ignore public costs and costs to the recreation and tourism sectors as well as boomtown effects, such as increased crime and crowded classrooms and the effects of the bust following the boom. Barth (2010) details, but doesn't quantify, many of these impacts. Christopherson and Rightor (2011) posit that to fully understand the economic impacts that shale gas drilling has on communities, one needs to look at long-term consequences (that is, economic development) and cumulative impacts (for example, new demands on government services, traffic congestion, noise, and social disruption), which input–output models ignore. Looking backward to past boom–bust cycles related to oil and gas development might help.

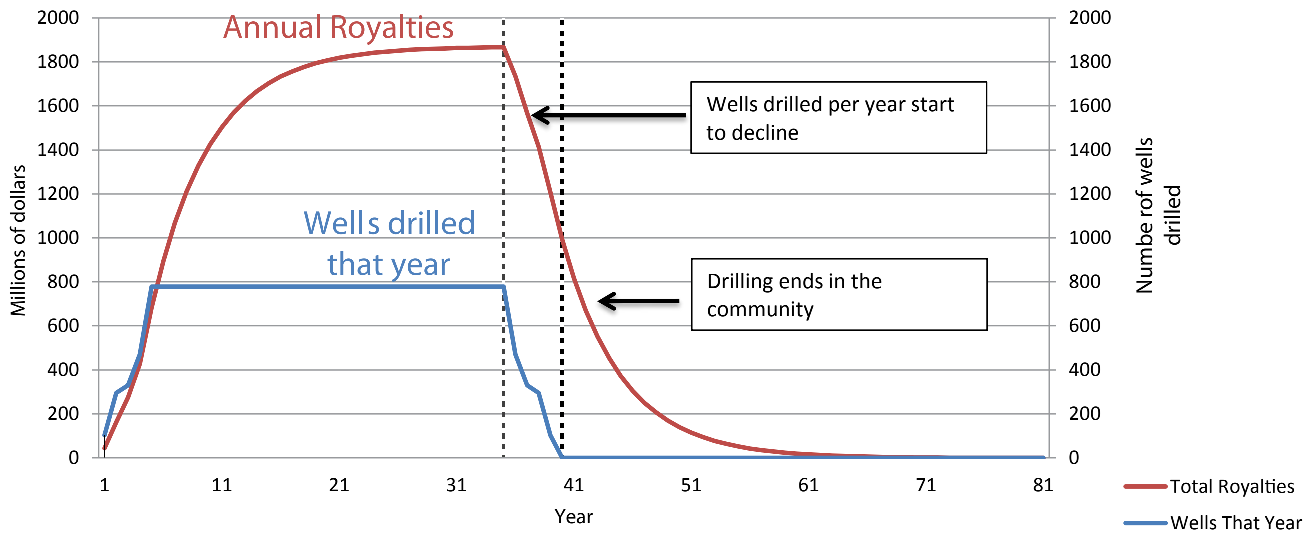
One example of increased government costs is crime impacts, in terms of enforcement and prevention. Kowalski and Zajac (2012) did not find "consistent increases" in Pennsylvania State Police incidents or calls for service or Uniform Crime Report arrests in the top Marcellus-active counties, but calls dropped in other counties over the same time period. In a comparison of disorderly conduct arrests in heavily "fracked" rural counties and in unfracked rural counties, Food & Water Watch (2013) finds a 4 percent greater increase in arrests in the fracked counties.

Boomtowns

The dynamic nature of economic impacts has generated a small literature specific to shale gas that adds to a very large literature on the boom-and-bust cycle in communities from all types of resource development.

Specific to shale gas, Christopherson and Rightor (2011) find that the pace and scale of drilling determine the duration of the boom and projected that, although the Marcellus region as a whole will experience a boom for years to come, individual counties and municipalities within the region will experience short-term booms and busts as

Figure 3. Annual Total Royalties in a Community



Source: Kelsey (n.d.), based on data from Cabot Oil & Gas.

production rapidly decreases in those areas. This cycle is displayed in terms of royalty payments in Figure 3.

The drilling of shale gas often requires an out-of-state work force, which causes increases in costs for local governments. Christopherson and Rightor (2011) note that with sudden community population increases come the need for more policing, more emergency response preparedness, more teachers, and larger schools. Though the increase in population causes temporary booms in certain sectors, such as hotels and restaurants, other local businesses that usually serve more traditional clientele may not share in the growth.

Taking a somewhat wider view (that is, oil and gas development and its effect on communities), Brown and Yücel (2013) find that communities or even states that are highly dependent on such developments for their revenues and gross regional product can be hurt when economic activity associated with a boom subsides.

In a recent statistical analysis of the boom phenomenon, using county-level census and other data for the United States, Allcott and Keniston (2013) find that oil and gas booms increase growth rates 60 to 80 percent over non-producer counties, with local wages increasing modestly (0.3 to 0.5 percent per year). In contrast to fears that such rising wages will cause manufacturing sectors to contract during a boom, in fact, manufacturing sector employment and output also rise (while falling along with decreased production during "busts").

Other county-level studies include Haggerty et al. (2013) and Weber (2012), both focusing on the West. Haggerty et al. find that although a boom increases county incomes, the longer a county is highly dependent on oil and gas development (the percentage of county income from this sector), the more per capita income growth erodes relative to counties with less and shorter dependence. Quality of life indicators, such as crime, are also correlated with this dependence (Haggerty et al. 2013). Conducting an ex post analysis in Colorado, Texas, and Wyoming, Weber finds that every million dollars in gas production created 2.35 local jobs in counties developing shale gas, a figure much smaller than economic input–output models project (Weber 2012). There are ongoing studies of the type by Weber, Allcott and Keniston, and Haggerty et al., so we judge that additional research on this issue may provide a lower value of information.

Critical Question 7.

Shale gas regulations should be informed by an in-depth cost–benefit analysis of various regions that have experienced the migration of businesses and people related to shale gas development.

What are the net benefits of shale gas development to local communities and how can they be maximized?

Sector Impacts

Shale gas development has the potential to impact industries upstream, midstream, and downstream of the production itself and, through the effect on prices, to impact sectors that use natural gas. Increased shale gas production also creates a greater demand for products such as proppants (fine sands used to prop open fractures in the shale and allow gas to escape) and fracking chemicals. In addition, it creates a demand for specific types of machinery, wastewater handling technologies, and other infrastructure. The products that result from new shale gas supply then can be used to spur other industries, such as manufacturing.

The electric utility sector is probably the most studied of those that use gas. Numerous studies have examined the effect of lower gas prices on electricity prices, generation mix, shares of generation fuel, and plant retirements and investments. Several of these studies (Brown and Krupnick 2010; Burtraw et al. 2012; Logan et al. 2013) agree in their estimations that more abundant gas has led to lower electricity prices, ranging from 2 to 7 percent lower. There is less consensus, however, on the magnitude of the change in natural gas consumption in the power sector.

Many reports on the impacts of shale gas development on other gas-using industries have been produced by the industries themselves. An example is the American Chemistry Council (ACC 2011), which finds that a 25 percent increase in the ethane supply (a natural gas liquid) would generate 17,000 new jobs in the chemical sector; 395,000 additional jobs outside the chemical industry; $4.4 billion annually in additional federal, state, and local tax revenue; and $132.4 billion in US economic output. Other reports include those of PricewaterhouseCoopers (2012), which is also on chemicals; Deloitte (2013) and Ecology and Environment (2011), on the natural gas value chain and indirect sectoral effects; and IHS Global Insight (2011), on general predictions about how shale gas development would impact various industries, such as chemicals, cement, steel, and aluminum.

Critical Question 8.

Relatively few studies address the downstream economic impacts of the shale gas revolution on gas-using industries, but there is significant interest from the public and private sectors in understanding these impacts.

How will the shale gas revolution affect employment, output, and investment activities for industries that are likely to benefit from lower natural gas prices (such as aluminum, cement, iron and steel, glass, paper, rubber, and plastics)?

National Economic Impacts

Few experts dispute that the US economy is benefiting, and will continue to benefit, from the innovations that made shale gas more accessible. Many studies classify benefits as more jobs, economic growth as measured by GDP (for example, from manufacturing revitalization), lower electricity and natural gas prices, improvements in trade balance (for example, from elimination of expected LNG imports and the LNG exports to come), and increases in tax revenues.

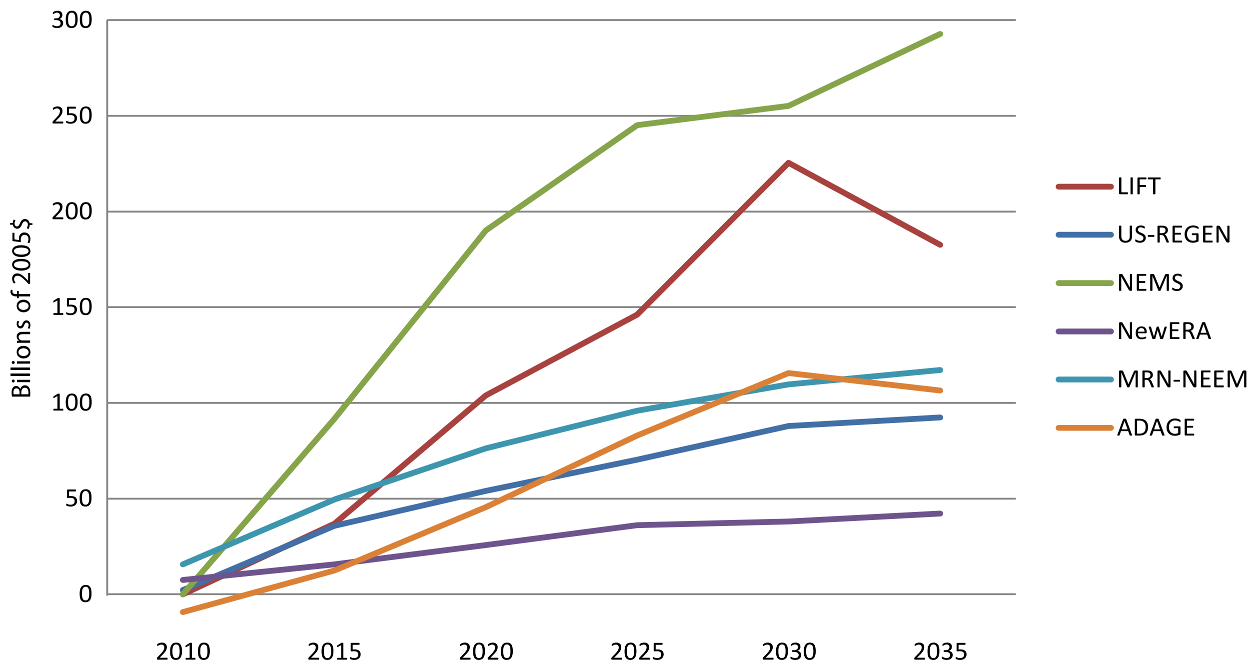
Studies differ in their findings regarding the duration and size of foreseeable economic effects—Boston Consulting Group on the high side, for example, (Plumer 2013) and EMF's multi-model study (EMF 2013) on the low side. Key factors explaining these differences include estimates of when the US economy will reach effective full employment, assumptions about future oil prices, what the supply curve for natural gas looks like at its upper reaches, whether the study takes an ex ante or ex post perspective, and the type of model used (input–output versus general equilibrium models, for instance). Nonetheless, the basic story on overall national economic benefit is the same.

A well-studied issue is the effect on the national economy of the US Department of Energy and the Federal Energy Regulatory Commission approving export licenses for LNG. Respected studies predict that the market for US LNG will be too limited to significantly increase natural gas prices in the United States (Montgomery and Tuladhar 2013; Deloitte Center for Energy Solutions and Deloitte MarketPoint LLC 2011). Therefore, the effects on the US economy will be minimal, as well.

The series of model results compiled by the EMF also sheds light on national economic impact, including GDP (most relevant for this section) as an output. These model results were generated under assumptions that are as similar as possible to allow a comparison of the results. In the EMF26 report (2013), the comparisons were set up to cover a reference case and up to seven other cases, including low shale gas and high shale gas resource cases.

To represent the impact of abundant gas supply on the economy, one must compare results for the low shale gas case (with cumulative production 50 percent below the

Figure 4. Change in Real GDP, High Shale Gas Case vs. Low Shale Gas Case



Source: EMF 2013.

Notes: ADAGE, Applied Dynamic Analysis of the Global Economy; LIFT, Long-Term Interindustry Forecasting Tool; MRN-NEEM, Multi-Region National–North American Electricity and Environment Model; NEMS, National Energy Modeling System; US-REGEN, US Regional Economy, Greenhouse Gas, and Energy.

projections in AEO2012 [EIA 2012]) and the high shale gas case (with cumulative production 50 percent above the AEO2012 projections) and report on models' forecast differences between the two. Six of the EMF models can produce these results, and they all show that the difference between the two cases on GDP is modest in percentage terms: an increase of less than 1.4 percent in any year. In absolute terms, the benefit is highest according to the National Energy Modeling System at about $300 billion in 2035; the other five models cluster between $50 billion and $180 billion in 2035 (see Figure 4).

As Houser and Mohan (2014) point out, the US should not expect enormous labor productivity and innovation impacts from the shale gas revolution. It is unlike the Internet and computer revolutions, which fundamentally changed our way of life and the way goods are manufactured, distributed, and sold. That said, the shale gas revolution significantly lowers (or even eliminates) our future dependence on foreign natural gas, helps our balance of trade from LNG exports, helps revitalize our gas-dependent manufacturing sectors through lower gas prices, provides energy savings to consumers of natural gas and electricity, and provides a source of rapidly

Environmental Impacts

ramping power to offset the intermittency of renewables, thereby helping renewables to grow, at least for a time.

Broadly speaking, the research issues covered in this section are concerned with building the "social license to operate." Because the scale of shale gas development has increased so quickly, the research community is playing catch-up in terms of understanding how large the environmental risks of shale gas development might be. This section covers the following:

- intermediate impacts to water quantity and quality (surface water and groundwater), air quality, and habitat;
- final impacts on the endpoints of human health and the health of ecological communities and species, including wildlife and domesticated animals;
- other impacts including induced seismicity;
- cumulative and scalar risks;
- how impacts are monetized and valued; and
- messaging about the impacts.

Water Quantity

The debates over water use concern whether withdrawals harm habitat and drinking water, whether consumptive use is large enough to affect the water cycle, and whether the quantity of water (and other liquids) requiring disposal is larger than the capacity available.

It is clear from the literature that the gross quantities of water being withdrawn are low per Btu of energy produced, trivial compared to withdrawals from other sectors (golf courses, for examples), and low relative to average daily flows of water in many source streams or rivers. What matters more is where and when water is withdrawn (Kuwayama, Olmstead, and Krupnick 2012). Freyman and Salmon (2013) show that, in some areas, even in "wet" states, further demands for water add to an already stressed source. Virtually no research has examined the actual impacts of water withdrawals on stream flow, habitat, drinking water, and agriculture (whether irrigated or not).

Because the total water used in shale gas development is so low, even high consumptive uses amount to trivial withdrawals from the water cycle. Indeed, according to Scanlon, Duncan, and Reedy (2013), by substituting natural gas in combined cycle plants for coal in power generation, water savings are from 25 to 50 times greater than the water used to frack the gas on a Btu basis.

Nevertheless, there remain issues of access to water, costs of access in regions where water rights exist or where wells are distant from water sources, place- and time-specific impacts of withdrawals on the ecosystem, increased traffic to move the water, and needed regulatory and engineering innovations to reduce water demands (Vaidyanathan 2013).

Critical Question 9.

Risks to surface water quality and quantity associated with shale gas development are a major concern of communities and operators alike.

How great are the risks to surface water quality and quantity? How effective are the various techniques and policies for mitigating such risks (in general and specifically in water-scarce areas)?

Water Quality

Surface water and groundwater can become polluted if fracking chemicals, flowback or produced water, or other drilling- or fracking-related materials are introduced. Regarding surface water, anecdotal, case study, and statistical evidence suggest that streams have been affected by sending wastes to publicly owned treatment works that are ill equipped to treat naturally occurring radioactive and briny influent and that, at least in the Marcellus shale, stream quality has not been affected systematically by spills at the sites, although runoff from drilling sites and associated roads and pipeline areas has raised turbidity (Entrekin et al. 2011; Ferrar et al. 2013; States et al. 2012; Vidic et al. 2013; Olmstead et al. 2012; Warner et al. 2013).

Regarding groundwater, the most contentious debate is whether fracking can result in pollution of groundwater by methane or other substances in produced and flowback water. Industry's position is that the capping rock is too impermeable for releases to occur. Some studies offer evidence of such pollution from deep deposits of methane (Osborn et al. 2011), but these studies have been criticized (Schon 2011) for not having good baseline data on pre-drilling methane in aquifers and water wells. Indeed, Heisig and Scott (2013) find that methane in drinking water wells is common in certain widespread geological and hydrological conditions. Issues with well cementing and casing meant to isolate an aquifer from the well are a standard problem in all oil and gas drilling. Industry would say this issue is fully manageable; governments say it can be mitigated (Heisig and Scott 2013). However, the scope of this problem is unknown. EPA will soon release a study focusing on these issues.

Critical Question 10.

The public is concerned about potential groundwater pollution from shale gas development. Industry could release data related to well integrity and from before and after testing of drinking water to shed light on these issues.

What is the magnitude and frequency of groundwater impacts from shale gas development, according to industry testing data (and other sources of data)?

Air Quality

Many of the activities associated with shale gas development generate "conventional" air pollutants through the burning of diesel and other fossil fuels. These conventional pollutants primarily include volatile organic compounds, diesel particulates, and nitrogen dioxide. Many types of toxic releases are also possible. Several studies show violations of air quality standards attributable to shale gas development and other oil and gas development activities in the West (Schnell et al. 2009; Stoechenius and Ma 2010; Rieman 2013; Lyman and Shorthill 2013), but this problem appears to surface in only a few localities. Nevertheless, more research is needed on this topic so violations of air quality standards can be more convincingly attributed to specific sources, whether oil and gas or others. For air toxics, studies measuring emissions and tracking their movement and transformation in the air are needed.

Habitat

The fragmenting of habitat by wells, roads, pipelines, and ancillary equipment can make it more difficult for ecosystems to provide essential ecosystem goods and services (Slonecker et al. 2012). The two primary effects are patch shrinkage and edge effects.

Habitat fragmentation from infrastructure development has been addressed in the literature, though less so than water quality impacts, and has recently been addressed more often by public news outlets (Sadasivam 2013). In an examination of land conversion in Pennsylvania, Drohan et al. (2012) conclude that the rapid conversion of core forest associated with headwater streams calls for increased monitoring for water quality impacts. Johnson et al. (2011), from The Nature Conservancy (TNC), take this study one step further and estimate land conversion for pipelines (including transport and gathering pipelines) and rights-of-way in Bradford County, Pennsylvania, concluding that 120,000 to 300,000 acres will be affected by pipeline construction, an area that is much larger than that required for natural gas wells, related roads, water containment, and staging and storing areas. More broadly, in Pennsylvania, 35 percent of state forest lands have been leased for drilling. Overall, TNC estimates that because of the 4,000 well pads it forecasts will be constructed by 2030, 61,000 acres of forest lands will be cleared.

Critical Question 11.

The impact of shale gas development activities on wildlife habitats is still unclear. Such information would be very valuable in identifying "optimal" siting for development.

How severe is habitat fragmentation as a result of shale gas development? How can impacts on habitat and biodiversity be reduced?

TNC is developing software that companies can use to help site well pads in such a way that will result in reduced ecological effects. Ultimately, such models should include pipeline and road siting as well as a means to balance the order and extent of lease holdings development against environmental impacts.

Human Health

Literally thousands of studies relate changes in pollutant concentrations in the environment to human mortality and morbidity risks. However, only one published study (Adgate, Goldstein, and McKenzie 2013) reviews the literature on public health risks from shale gas development, although most of the review is about potential impacts. Indeed, Adgate, Goldstein, and McKenzie (2013, 2) state that "no comprehensive population-based studies of the public health impacts of unconventional natural gas operations have been published." A more recent draft study from Public Health England (Kibble et al. 2013) also addresses this topic. These authors rule out similar concerns about exposure to naturally occurring radioactive materials, but they do so on the basis of very little evidence from English exploratory wells and on the assumption that proper waste handling techniques are followed.

In a provocative study, Hill (2012) estimates infant health impacts linked to shale gas drilling in the Marcellus shale region and concludes that low birth weights were 25 percent more common in mothers who lived within 1.5 miles of gas development than those who lived farther away. The same researcher conducted a similar study in Colorado, where similar results were found (Hill 2013).

Experts at RFF and at Geisinger Health System are also conducting research in this area. In particular, researchers are estimating the relationship between shale gas development in Pennsylvania over space and time as related to truck traffic and the frequency and severity of traffic accidents, with severity measured according to whether serious injuries or death resulted. One preliminary analysis reports "that one additional well drilled per month raises the frequency of accidents involving a heavy truck by more than 2 percent" across the counties with more than 20 wells developed, which further translates into a 0.6 percent increase in mortalities (Muelenbachs and Krupnick 2013). Further research will be able to better target these statistical associations to specific truck routes affected by shale gas development.

Critical Question 12.

The public is concerned about potential health effects from shale gas development, yet there are few studies that adequately demonstrate the impacts.

How has public health (both mental and physical) been affected by shale gas development? What potential future impacts exist? And how could such impacts be reduced through policy?

Ecosystems and Species

The US Geological Survey (USGS) provides a framework for considering ecological impacts from oil and gas development, though it is not unique to shale gas. This framework divides effects into terrestrial and aquatic (Bowen and Farag 2013). USGS also examined the effects of brine contamination from oil well development on aquatic resources in the Williston Basin in northern Wyoming (Preston et al. 2014).

Considering animal health, many scientific studies have focused on a single specific impact on a species following exposure to natural gas and natural gas production chemicals or other aspects of the development process. For instance, Waldner et al. (1998) studied the impact of natural gas leaks on the productivity of beef cattle. Although some authors have concluded that exposure to gas drilling operations can have serious health effects on companion animals and farm animals, Waldner , Ribble, and Janzen (1998) find no correlation between herd calf mortality and distance from a gas leak.

Sawyer et al. (2006) used GPS to follow mule deer movements during development of a natural gas field in western Wyoming. They find the deer avoid the area of development and move into areas of less desirable habitat, assuming that areas less used before development were less desirable. The importance of such impacts is another matter (Sawyer et al. 2006). However, a subsequent report finds a 60 percent shrinkage of the mule deer population in western Wyoming (Sawyer and Nielson 2010).

Shale gas development may have direct effects on fish and wildlife species, some of them endangered or threatened. Among the species potentially affected are the kit fox, blunt-nose leopard lizard, California condor, mountain plover (Center for Biological Diversity, Sierra Club, and Los Padres ForestWatch 2011), and sage grouse. In particular, the US Fish and Wildlife Service concludes that drilling in sagebrush habitat "poses a serious threat" to the greater sage grouse (DOI 2010). As Adams (2011) puts it, "We were surprised by the paucity of peer reviewed research evaluating effects of natural gas development on forest lands in the eastern United States…. In general, information about effects on most fauna also is lacking."

Other Impacts

Other potential nonmarket impacts include recreational damages (such as those resulting from habitat reduction, loss of hunted populations, and loss of forested area available for hiking and camping) and seismic damages, either at well sites or at deep well injection sites. Seismic impacts have gotten the most press, but the academic literature strongly leans toward the view that seismic impacts from fracturing per se are trivial. Impacts from liquid waste injection into Class II wells are of greater concern; the largest quake thought to be induced by deep well injection (5.7 on the Richter scale) was in Prague, Oklahoma, resulting in two injuries and 14 homes destroyed (Gilmer 2013). At the same time, quake magnitudes are generally small. USGS and state agencies continue to study earthquake records in Oklahoma and elsewhere and believe that wastewater disposal is a contributing factor (USGS 2013; Soraghan 2013).

We found no studies of the lost recreational opportunities in areas with very dense shale gas and other types of extractive activities. More study is also needed on the effects on agricultural productivity where the water supply is highly constrained.

Cumulative and Scalar Risks

The sections above discuss risks one at a time. Yet impacts and even valuation of those impacts can act synergistically, such that the whole is greater (or less) than the sum of its parts (*cumulative risk*) and can grow with development over time (*scalar risk*).

Virtually no papers exist on this topic. In the first exploratory effort, Krupnick and Olmstead (forthcoming) examine the cumulative and scalar risks of potentially greatest concern. They consider a series of questions on this topic, such as the following: How do these risk pathways, representing an assortment of both stock and flow burdens, change as the scale of shale gas development increases? Do these pathways interact in important ways with each other, with other environmental conditions, or with the behavior of firms, regulators, and exposed individuals? Will risk mitigation strategies have synergistic effects, reducing risks from multiple pathways at the same time?

Olmstead and Krupnick conclude that little is known about the degree of scalar and cumulative risks; such knowledge would aid in gauging the priorities by which various risks should be addressed.

Valuation

Ultimately, monetizing the health and ecological impacts of shale gas development is critical for a cost–benefit analysis of regulations and best practices. This can be done in several basic ways, including stated and revealed preference approaches. The stated preference approach uses surveys to elicit participants' valuation (economists use the term "willingness to pay"). The revealed preference approach uses statistical techniques to infer willingness to pay from behavior. "Hedonic price" models are a good example—they help explain differences in market prices (property sales, for example) by using data on various polluting activities or pollution levels as well as property characteristics.

RFF researchers Juha Siikamäki and Alan Krupnick (2013) conducted a stated preference survey of Pennsylvania and Texas residents, concluding that most respondents are worried about environmental risks, especially those related to groundwater and surface water, but a fraction is not concerned about any risks. Respondents in both Texas and Pennsylvania were willing to pay between $20 and $30 per year to eliminate risks for 1,000 drinking water wells (Siikamäki and Krupnick 2013). Bernstein et al. (2013) also conducted a survey, from which they conclude that "households are willing to pay an average of US$12.00 per month for public projects designed to improve river access and US$10.46 per month for additional safety measures that would eliminate risks to local watersheds from drilling for natural gas from underground shale formations."

Critical Question 13.

Understanding the public's willingness to pay for risk reductions is key for estimating the benefits of risk mitigation activities. This requires the use of stated and revealed preference approaches.

How much is the public willing to pay to reduce risks associated with shale gas development?

Messaging

Some experts would argue that problems with the social license to operate are associated more with ineffective messaging and a lack of public trust than with "real" risks. Siikamäki and Krupnick (2013), as part of the above referenced study, find that the environmental community's messages are far more effective than industry's. Specifically, nongovernmental organizations are adept at reducing support for shale gas development, whereas the industry's messages (as taken from API's website) are just as likely to increase opposition and concerns about risks as to increase support and reduce risk concerns.

Regarding building public trust, Christopherson, Frickey, and Rightor (2013) conducted a study of local communities within the Marcellus shale region that have taken action to delay drilling operations or restrict certain shale gas activities. Their findings suggest that the need for government action comes from the public's distrust of the oil and gas industry or the industry's lack of willingness to take action to protect local communities from harm during shale gas development.

Nakagawa (2013) compiled a list of actions that oil and gas companies can take to build a community's trust in the industry. Although Nakagawa focuses on potential actions that can be taken after the industry has entered a community, Cotton (2013) emphasizes the importance of engaging with communities early, when opportunities still exist for the public to have input on siting and community benefits, and for building partnerships between local community groups and developers. Cotton categorizes different community groups and recommends possible engagement strategies for each group.

Critical Question 14.

The erosion of public trust in institutions is a major roadblock to sustainable shale gas development.

How can public trust in institutions, both government and the oil and gas industry, be enhanced?

Abundant Gas and Global Climate Protection

Among all fossil fuels, natural gas emits the least CO_2 per unit of energy when combusted. Widespread substitution of natural gas for coal and petroleum in electricity generation, industrial processes, and transportation could significantly reduce greenhouse gas (GHG) emissions (depending on the volume of fugitive methane emissions). But natural gas could also substitute for nuclear and renewable energy, raising CO_2 emissions above those that might have occurred with more expensive natural gas.

Within this framing, this section covers the following topics related to abundant gas, carbon emissions, and climate change:

- how natural gas might substitute for lower or higher carbon fuels, particularly in the power sector;
- what is known about rates of fugitive methane emissions from natural gas production and distribution; and
- how natural gas could fit into global climate change goals related to specific temperature or concentration limits.

The Natural Gas "Bridge": Substitution for Other Fuels

A number of commenters have suggested that abundant, low-cost natural gas could act as a low-carbon energy "bridge" to the near-term future by lowering global GHG emissions through fuel switching while renewable and other low-carbon energy technologies mature and become economically viable. Natural gas has also been suggested as a complement to renewables by filling in the load curve; this would come about from the ability of "fast-cycling" gas plants to backstop the intermittency of renewables.

A tenet of the natural gas bridge case is that abundant gas and accompanying low gas prices will act through energy markets alone (that is, in the absence of government imposed GHG mitigation policy) to displace fuels with higher carbon content and thereby reduce emissions. Proponents point to the recent US experience as support for this, although other factors to reduce emissions are also at work. These other factors include many state-level programs designed to foster the deployment of renewable electricity, as well as the decline in the growth of household-level electricity demand.

To examine the natural gas "bridge" concept, researchers at RFF conducted a study (Brown and Krupnick 2010) using the public access version of EIA's NEMS model (EIA 2009). Two scenarios were developed and, in both, only existing climate polices were included. The first scenario—conservative gas—utilized the baseline analysis EIA conducted using NEMS for the 2009 Annual Energy Outlook. The second—abundant gas—used natural gas resources estimates from the Potential Gas Committee in 2009 that were over twice the resources estimates contained in AEO2009 and more in line with the supply relationships of today.

Brown and Krupnick (2010) found that natural gas consumption in the abundant gas scenario increased 11 percent by 2030 beyond the conservative gas case and increased 22.5 percent in the electricity sector. The increase in natural gas use in generation came at the expense of coal, nuclear, and renewables. Electricity prices were 7 percent lower in 2030 and CO_2 emissions were about 1 percent higher in the abundant gas case.

However, in a second study by RFF researchers (Burtraw et al. 2012), utilizing the RFF electricity model (HAIKU) and focusing on a shorter time frame (2010 to 2020), abundant gas in the form of lower cost gas prices primarily displaced coal in the electric utility sector and lowered CO_2

emissions (all other environmental regulations constant) by 10 percent in 2020. In this recent analysis, the expansion of gas did not come at the expense of renewables. Gas displaced coal due simply to the gas-coal price spread, but because the continued deployment of renewables over the rest of this decade is driven in the model by state-level renewable portfolio standards (RPS) rather than market prices, low-cost gas has no impact on renewables.

These two apparently contradictory results are resolved by noting that the first is for 2030 and the second is for 2020. The effects on renewables can only occur once state-level RPS policies are nonbinding. In further unpublished research, the RFF team found that renewables generation was 5 percent less by 2030 than it would have been, in comparing the gas resource base in AEO2009 with that in AEO2011. More research is needed on the extent to which mandates and other policies to promote renewables (tax credits, loan guarantees, subsidies, and so on) drive a wedge between the gas–renewables market spreads and thereby dampen the impact of lower gas prices on the deployment of renewables.

In addition, a recent study by RFF researchers (Paul et al. 2013) evaluated the impacts on usage of coal, natural gas, renewables, and nuclear to generate electricity in the United States when carbon emissions were taxed at varying levels. Under the low carbon tax scenario, emissions reductions are achieved through reductions in coal-fired electricity generation and end-use electricity consumption, along with an increase in natural gas–fired generation. At higher tax levels, expanded use of lower carbon–intensity electricity generation resources—that is, renewables (mostly wind) and nuclear—would help offset reduced coal generation. For a high enough carbon tax, increased natural gas generation will cease to help offset reduced coal generation and will instead be displaced, like coal, by cleaner generation sources.

Looking at the global scale, researchers at the Joint Global Change Research Institute (JGCRI) recently used their large-scale, global change assessment model (GCAM) to examine the natural gas bridge on a global and far longer time scale. The JGCRI team ran the GCAM through midcentury (2050) under two gas scenarios (Flannery, Clarke, and Edmonds 2013). In the first, natural gas is viewed from the year 2000, where large global gas resources exist but they are too costly to exploit on a grand scale. In the second (circa 2010) the same gas resources exist, but they are extractable at considerably lower cost. The 2010 scenario is designed to mimic current understanding of future gas availability and pricing.

Not surprisingly, natural gas production and use expand globally under the abundant gas scenario and are 37 percent greater in 2050 than they are predicted to be under the more conservative supply and pricing case. Consistent with both RFF studies, gas expands its share in all energy sectors with the greatest increase coming in electric power generation displacing coal and renewables (10 percent less coal, 10 percent less renewables). Emissions of CO_2 from coal decline 12 percent, but lower gas prices lead to lower electricity prices and a 3.7 percent increase in electricity consumption. Most important, there was no difference in CO_2 emissions between the conservative and abundant gas scenarios—that is, the widespread market penetration of gas did not lower CO_2 emissions in the absence of government mitigation policy. The result that abundant gas does not reduce emissions is due to offsetting factors. While gas does displace high-carbon coal, it also displaces zero-carbon nuclear and renewables. Importantly, lower-priced gas leads to increased electricity generation from all fuel types.[6]

Critical Question 15.

The role of natural gas in reducing global CO_2 emissions is unclear. Understanding this is crucial for countries such as China and India, where rapid growth in electricity (and natural gas) demand is expected.

How will current levels of CO_2 emissions be affected when natural gas substitutes for coal and nuclear power in electricity generation? How will these substitutions affect renewables penetration in the short and long term? How much will demand for electricity increase because of lower natural gas prices?

Fugitive Emissions

As noted above, when natural gas is combusted, it produces CO_2, but about 50 percent less per Btu than coal. However, when natural gas is released in its uncombusted form as methane, it has a global warming potential at least 32 times (and for a short time horizon, 72 times) that of CO_2. The life-cycle GHG emissions of natural gas extracted from shale is an area of intensive academic research and regulatory attention focusing on fugitive methane from drilling, well fracturing and completion, and other stages of the development process.

The most well-known (and controversial) study, conducted by researchers at Cornell, found that shale gas is not a cleaner energy source than coal when full life-cycle emissions, including fugitive emissions, are taken into

[6] The modelers have assumed that fugitive methane emissions increase proportionately with gas production, but are somewhat offset by lower methane emissions from coal.

account (Howarth, Santoro, and Ingraffea 2011). Shortly after that study was released, the National Energy Technology Laboratory released its own natural gas extraction life-cycle analysis, disputing the findings of Howarth, Santoro, and Ingraffea. Since then, the Cornell study has been refuted many times. Almost all researchers now acknowledge that the Cornell estimates involve a significant mischaracterization of methane leakage.

Almost every paper on the debate over shale gas and GHG emissions has eventually called for better research on venting, flaring, and fugitive emissions rates throughout the natural gas production and transmission process. Two new studies help fill this gap. A recent study by EPA (2013) using industry data suggests that fugitive emissions are relatively low and not a major concern. Another study, sponsored by the Environmental Defense Fund (EDF) and limited to the production stage, aligned with EPA's estimates for this stage, although the emissions from the individual components of this stage were radically different from EPA's estimates (Allen et al. 2013). (Also, the EDF study focused on a small sample of wells operated by companies that self-selected to join the study.) However, two new studies (Pétron et al. 2013; Pétron et al. 2012) using different measurement methodologies (in this case air monitoring methods—both stationary and mobile) suggest that emissions are greater than those estimated by EPA or EDF—more than enough to negate the positive CO_2 impacts of the switch from coal to gas.

Critical Question 16.

More studies on fugitive methane emissions are required to build a consensus on their magnitude relative to the GHG emissions from coal combustion in the United States and elsewhere.

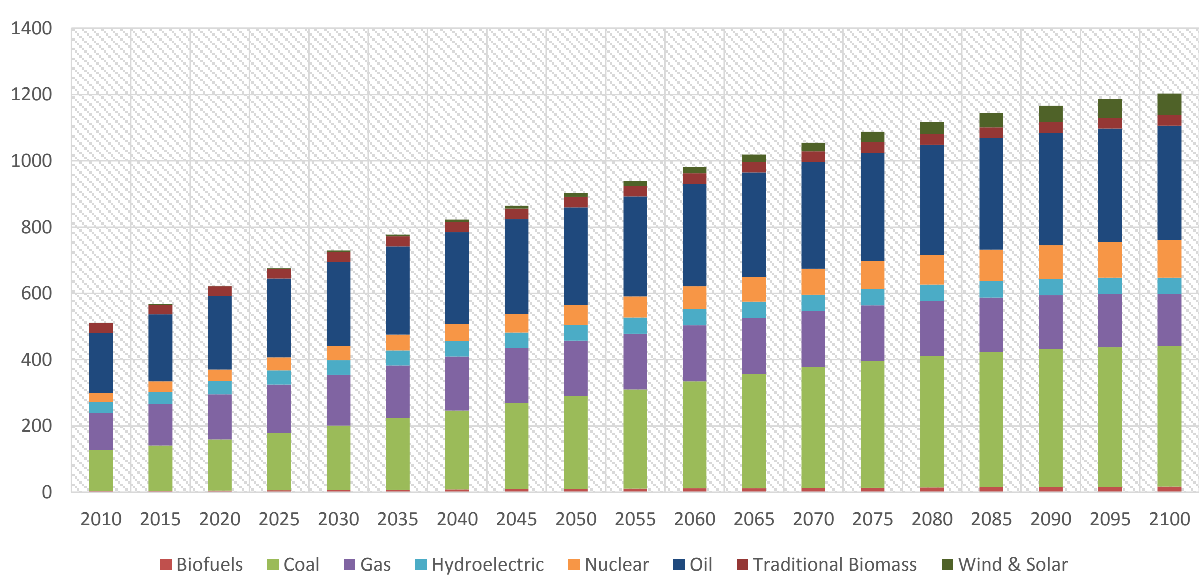
How will expanding gas extraction activities in Russia, the United States, and other major current and future gas suppliers affect global GHG emissions levels?

Aggressive Emissions Goals

The 2013 G8 meeting in Lough Erne, Northern Ireland, included a statement on GHG mitigation goals as part of the meeting-end declaration. This goal of limiting the global mean temperature increase to 2°C above pre-industrial levels can be equated to a global GHG concentration target of 450 parts per million (ppm) by the end of the century. Large-scale integrated assessment models (IAMs) can be used use to examine GHG mitigation paths that are consistent with that goal.

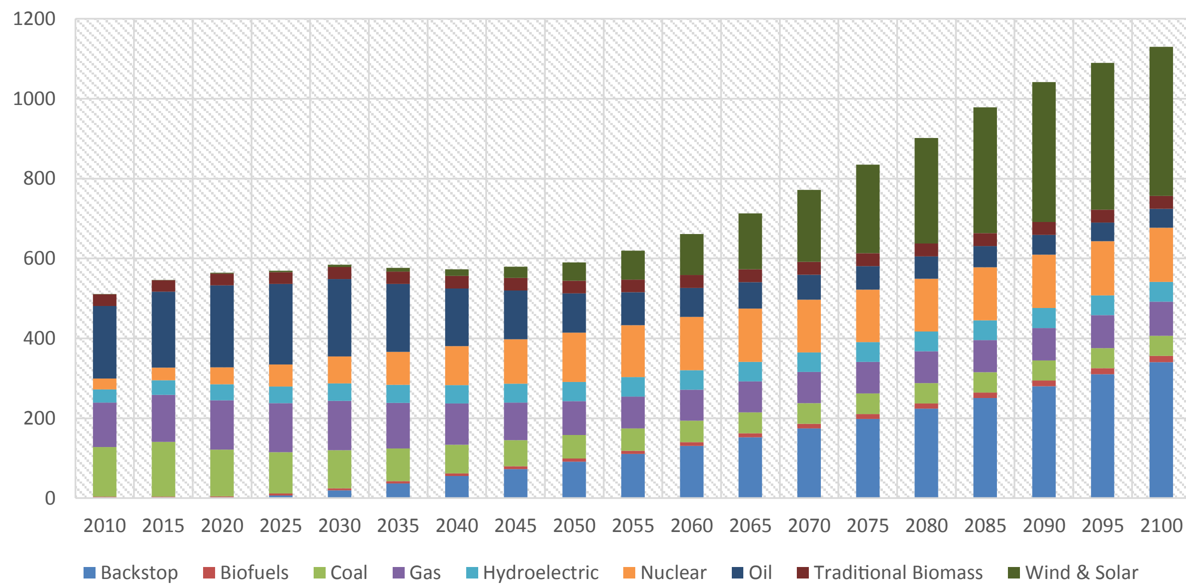
There are many IAMs that can be used to perform this analysis. One such model that allows public access to results is Fondazione Eni Enrico Mattei (FEEM)'s World Induced Technical Change Hybrid (WITCH) model. Below are the results of two scenarios. The first scenario is a business as usual (BAU) scenario, in which no global policy is in place to constrain GHG emissions over the next

Figure 5.1. Global Energy Use under Business as Usual (exajoules)



Source: FEEM 2010.

Figure 5.2. Global Energy Use under a 535 ppm Stabilization Scenario (exajoules)



Source: FEEM 2010.

century. The second constrains global GHG concentrations to 535 ppm (considerably above the 450 ppm goal). These are results from a single model and should be viewed as such.

Figure 5.1 plots the global use of various forms of energy over this coming century under BAU assumptions. The measure of energy use is exajoules. The figure illustrates that gas use rises through midcentury and begins a slow decline, but is still 40 percent greater at the end of the century than it is today. Figure 5.2 depicts energy use by fuel to meet a 535 ppm concentration goal. Under this scenario, gas use rises about 8 percent to 2030 and then declines throughout the rest of the century (due to GHG constraints). In 2060, gas use is about 70 percent of current use and remains at approximately that level for the rest of the century. Importantly, the 535 ppm scenario assumes there is no carbon capture and storage (CCS) fitted to gas use. If CCS were available, it would be fitted to gas combustion processes after 2035 and gas use would remain about 15 percent above current consumption by the end of the century.

Although gas combustion produces less GHG emissions than coal, it still produces some. For some less aggressive GHG emissions reduction goals, gas can substitute for coal and be part of the mitigation strategy. However, as the goal becomes more aggressive, gas plays less of a role, and for very aggressive goals, it must be combined with CCS to remain within the feasible fuel mix.

Critical Question 17.

Recent global modeling of aggressive GHG mitigation policies suggests that large-scale natural gas use will require carbon capture and storage (CCS) early in the century to support such policies; however, such aggressive goals require equally aggressive government policies.

Looking at the top greenhouse gas emitting nations, what role can be played in the early part of century by gas without CCS and what relaxed emissions reductions goals are consistent with that gas use? resources to meet GHG emissions reductions goals?

Regulation, Best Practice, and Liability

This section focuses on the roles that government (through regulation and enforcing liability laws) and industry (through best practices and other voluntary efforts) play in mitigating risks from shale gas development. The literature in these areas is expanding but is, by and large, descriptive rather than analytical. In this section, therefore, we devote most of our attention to those studies that describe not only what regulations or best practices exist, but also how well they are working, how stringent they are in a comparative sense, and which level of government is appropriate for particular types of regulations.

Regulatory Frameworks

Outside of federal lands and offshore production, states remain the primary venue for most oil and gas regulation. However, federal authority over some parts of shale gas development is significant, particularly regarding the protection of air and surface water quality and endangered species. Interstate river basin commissions generally have no regulatory authority, but two that do have jurisdiction over important water resources for development in the Marcellus shale. Local governments also play a role through zoning and other authorities.

Federal

In the legal literature exploring the federal regulatory role in shale gas development, one common critique is that oil and gas activities are exempt from many core environmental laws. Burger (2013) explores exemptions for certain oil and gas and shale gas activities from the Safe Drinking Water Act and Resource Conservation and Recovery Act; he suggests certain considerations that may justify federal regulation. Fershee (2012) also explores risks and suggests that EPA should require compliance with API best practices for hydraulic fracturing. Much of the literature takes on federalism issues, as described below.

The federal government—primarily through the Bureau of Land Management (BLM)—directly regulates shale gas development on public lands. Some observers have expressed hope that BLM will set a regulatory example that states could use as a model; others have criticized BLM as being slow to award leases and permits. Feiden et al. (2013) point out that BLM's revised rules for hydraulic fracturing on federal and Indian lands, released in May 2013, represent a significant weakening of the May 2012 proposed rules, and that they are generally less stringent than existing state regulations (which also apply on federal lands). The authors conclude that the BLM regulations are best focused on those areas where a state has failed to regulate a risk or where the consequences of development are greater on public lands (Feiden et al. 2013).

The federal government is just beginning to play a role in providing data, money, research, and expertise to improve the sustainable development of shale gas. This role is important because it can save states from duplicating efforts and can help build trust in the regulated sectors. In terms of policy, one bill recently introduced into the House (HR 1900) would expedite gas pipeline approvals.

State

About 27 states are actively discussing or pursuing shale gas development; another 4 (Vermont, New Jersey, North Carolina, and Georgia) may have shale gas resources (see Figure 2 above for map). Organizations such as the State Review of Oil and Natural Gas Environmental Regulations (STRONGER) provide in-depth reviews of regulatory activities in a given state, but these reviews are not comparative.

It is quite difficult to get comparable information on regulations across states and even more difficult to get enforcement and monitoring data. A number of efforts have compared regulations across states (Richardson et al. 2013; Gosman 2013; Wiseman 2012), generally concluding that state regulations are quite heterogeneous, although they overwhelmingly use command-and-control approaches. This observation has led some researchers to propose more formal state comparisons and updates of regulations. It has also led some organizations, such as the National Governors' Association, to convene state leaders to share experiences. The proposed creation of state exchanges by the Interstate Oil and Gas Compact Commission and the Groundwater Protection Council is an expression of this interest; under such systems, states would share information about regulatory developments and behavior. Another common theme in these studies relates to the difficulty of obtaining information from some states; several authors have called for greater data availability and transparency. In particular, data from permits are generally unavailable to the public.

Many states are revising their regulations (tightening them, in almost all cases), partly in response to the unique challenges posed by shale gas development. Suggestions for shaping these new regulations have come from a number of observers and advisory bodies—perhaps most notably the Shale Gas Production Subcommittee of the Secretary of Energy Advisory Board (2011). The Governor's Marcellus Shale Advisory Commission similarly provided guidance for Pennsylvania.

Critical Question 18.

Shale gas development has grown very quickly, often leaving states to "catch up" in determining the best approaches for regulating such activity.

How can state regulation of shale gas development—including monitoring and enforcement, and the regulations themselves—be improved? How can they be more cost-effective?

Local

The authority of counties, cities, towns, townships, and other local governments over oil and gas development varies substantially among the states. Most states have delegated authority over land use, noise, zoning, and so on to local governments, yet the degree of delegation varies widely. This has been important in the context of shale gas because some municipalities have attempted to assert control over development and its impacts—in some cases banning it. A small literature on local regulatory issues has developed (Kennedy 2011; Freilich and Popowitz 2012; Watson and Pincus 2012), although it is generally descriptive. To the extent that states already delegate significant authority to local governments (as in Texas) or may do so in the future, data on these rules will be important for understanding and comparing state rules.

Federalism

As the dominant regulatory bodies in oil and gas, including shale gas development, states have developed relationships with industry that appear to these parties to work well. Much discussion in industry and policy forums, including those focusing on governance, presumes that this state leadership should continue—yet those who want to see a greater role played by federal or local governments present numerous challenges to state dominance. Some (but not all) of these challenges come from those who desire more stringent or less stringent regulation and feel that federal or local control will be more likely to lead to that result. Debates over the division of regulatory authority among levels of government—federalism—are likely to continue. Indeed, the recent ruling by the Pennsylvania Supreme Court that the state's Act 13, which limits the ability of local governments to regulate shale gas development, is unconstitutional may tip the balance more in favor of local control.

Several authors have explored the justifications for why certain levels of government should have authority over shale gas development (Nolon and Polidoro 2012; Spence 2012; Lowry 2013; Davis 2013). One theme from this work is that environmental risks are best regulated by the level of government whose jurisdiction most closely matches the geographic extent of the externalities that might result from the regulated activity. Other considerations—including capacity to regulate, costs associated with changing the historic division of authority, and connections between development and state or national policy goals—are also involved.

Limited theoretical and practical research has addressed federalism specifically related to shale gas development, and what does exist has reached contradictory results. For example, among legal scholars, Spence (2012) argues that little justification exists for increased federal regulation, whereas Freeman (2012) asserts that federal minimum standards are needed, with both authors pointing to many of the same principles for justification. Rabe (2013) presents two alternatives for considering states as the primary regulators: states could "race to the bottom" and be captured by industry, or, states could "race to the top" amid a flurry of cross-state cooperation or pressure from local governments. For shale gas, Rabe is concerned about the capacity of states and localities to govern with the growing partisan divide, where one party controls both the legislature and the governorship.

Case Study: Disclosure Policies

Information disclosure policies have been developed to inform consumers about the public and private benefits of their consumption activities and to influence the behavior of polluting firms. Some disclosure requirements have been implemented in an effort to mitigate shale gas development risks at both the federal and the state levels, primarily related to fracking fluid. Currently, 15 states require some type of fracking fluid disclosure, as seen in Richardson et al. (2013, Figure 6), and BLM included a fracking fluid disclosure requirement in its May 2012 draft rules for hydraulic fracturing operations on public lands.

In addition, FracFocus—the national hydraulic fracturing chemical disclosure registry managed by the Groundwater Protection Council and the Interstate Oil and Gas Compact Commission—has emerged as the voluntary means of making chemical disclosures, as well as the place referred to in state regulations for mandatory disclosures. The FracFocus website allows users to obtain lists of fracking fluid chemicals by well. This site has both supporters and detractors. Those who have argued for fracking fluid disclosure policies presumably anticipated that disclosure would result in significant public attention to operators using toxic chemicals, creating pressure for a change in the toxicity of the fluids and how they are managed. Those who have been critical of the effort have argued for greater ease in data handling on the website and that contributions to the site from operators should be mandatory. Because disclosure through FracFocus has occurred for some locations since 2011, an empirical assessment of its effects on fluid management may now be feasible. Tracking the evolution of the chemical composition of fluids may also be possible.

Critical Question 19.

Debate continues about which levels of government should have the authority and responsibility to regulate shale gas development. Informing this debate will require both empirical and applied research from various disciplines including law, political economy, and economics.

What aspects of shale gas development can and should be regulated at the federal, state, and local levels, and can such an approach be applied across states?

Monitoring and Enforcement

The effectiveness and cost-effectiveness of regulation cannot be evaluated by regulatory stringency alone; evaluations also need to capture monitoring and enforcement efforts and successes. Because these efforts are generally well reported on, few studies in this area are available. Wiseman (2012), however, examined enforcement activity for shale gas and tight oil development in four states, considering which stages of the well development process lead to the most violations. She concludes that states should focus their enforcement efforts on stages that pose higher environmental risks (for example, underground water testing, proper casing and cementing of wells, and chemical transportation).

The Western Organization of Resource Councils (2013) also examined monitoring and enforcement practices in five western states, looking at measures of enforcement input (number of inspectors per active well and number of inspections per period) and output (number of enforcement actions as a fraction of inspections and wells). The conclusions are ones frequently heard in the literature: ratios of inspectors to wells are falling and, although inspections are generally occurring more frequently, the workload is very substantial. States have a mixed record on transparency, and only two of the states follow and report complaints and agency responses.

A final example is a Pennsylvania Land Trust Association (2010) fact sheet on the source of violations, about one-third of which were judged unlikely to harm the environment. Overall, the bulk of violations were for improper erosion plans, the discharge of industrial waste, improper waste impoundment construction, and faulty pollution prevention. In an analysis of average violations per well by company, the majors look better than the smaller companies.

Best Practices: Voluntary Industry Behavior

Voluntary behavior can take several forms, from companies trying to improve technologies and procedures to minimize risk (or better apply technologies and procedures already in place) to individual institutions or collaborations supporting efforts to codify best practices or model behaviors for the sector. Some efforts are led by industry groups, whereas others bring together nongovernmental organizations, industry, and other stakeholders; these efforts have resulted in a number of recommendations and reports.

Beyond understanding what is contained in each document recommending best practices, it is arguably more important to evaluate or compare the success of these approaches. Few such studies exist, but one good example is Bearer et al. (2012), who evaluated 28 best management practices from a variety of stakeholder groups addressing impacts from shale oil and gas activities on wildlife and habitat. These authors concluded that most best management practices are too general and that a greater appreciation of site specificity is needed.

An RFF report reviewing state regulations (Richardson et al. 2013) contains a limited comparison of state regulations to API best practices. According to API, its guidelines are designed to meet or exceed federal standards while remaining flexible enough to accommodate variations in state regulations and conditions. Nevertheless, Richardson et al. found it highly challenging to compare API's recommendations with state standards because API uses general and performance-based language, whereas the states largely use more specific, command-and-control regulations.

Critical Question 20.

At least 20 guidance documents for industry best practices have been produced by a variety of stakeholders—but there are no studies that compare these guidelines or take the next step of comparing those findings to regulations.

What is the appropriate role for best practice guidelines (voluntary behavior by industry) versus government regulation?

Liability

Although virtually all public discussion of the risks of shale development revolves around the proper role for regulation, it is arguably liability, not regulation, that is the most important driver of operator practices aimed at reducing risks—and this would probably remain the case under even the most ambitious proposals for more extensive regulation. Indeed, hydraulic fracturing and shale drilling litigation has rapidly increased since 2009 (Kurth et al. 2011).

Options for improving the liability system are relatively underexamined. Olmstead and Richardson (forthcoming) explore several possibilities, organized broadly around principles in Shavell (1984). These options include (a) improving information asymmetry among regulators, operators, and the public; (b) creating financial or insurance mechanisms to ensure that operators can make good on liability claims; (c) designing stronger financial responsibility requirements; and (d) moving to reduce the cost and complexity of class-action suits to reduce the ability of operators to escape liability for disparate harms. Information disclosure rules are also useful in that they enable actual and potential victims to find out about harms, identify responsible parties, and establish causation in litigation.

Comparing Regulations, Liability, and Best Practices

No literature compares all three approaches to risk mitigation specifically for oil and gas applications, although many authors have discussed any two of these in other contexts. Olmstead and Richardson (forthcoming) compare liability to regulation, with an emphasis on performance standards, and Richardson et al. (2013) compare performance and command-and-control standards as well as regulation more broadly with liability. Richardson et al. conclude that small changes to the liability system may be simpler and more cost-effective than new regulation. Advocates for legal change in response to the risks of shale development should not ignore these options.

Critical Question 21.

Discussions about improving shale gas development often refer to developing more and better regulations and/or encouraging such behavior through voluntary industry activities (best practices). However, holding companies liable for their actions (the liability system) is the often-ignored third leg for improving industry practice.

In considering regulation, best practices, and liability, what are the strengths and weaknesses (including cost-effectiveness) of the three approaches? Under what circumstances are these approaches substitutes or complements?

International Markets for Natural Gas

In 2012, total international trade in natural gas amounted to 35 tcf, including 10 tcf of LNG and 25 tcf as pipeline gas (BP 2013). However, over the last half decade, LNG trade has grown considerably faster than trade in pipeline gas due to expansion of liquefaction facilities and strong Asian demand.

The expected growth in the international market for natural gas will be dependent on four factors touched on in this section:

- the regional pattern and growth of gas consumption;
- the changing geography of gas production and international supply;
- the pattern of global investments in gas transportation infrastructure; and
- the reform and evolution of contract and pricing policies for internationally traded gas.

Consumption

Natural gas is an increasingly valuable fossil fuel used in all sectors of the global economy. As global economies expand over the next few decades, the use of gas in industrial applications for combined heat and power, process heat, and as a feedstock in chemical manufacturing will continue to increase. Recent growth in gas consumption (in terms of total quantity consumed and in percentage terms) has been very strong in the Asia Pacific region.

The sector of the global economy in which consumption will be the greatest going forward is in electric power generation, where gas is a direct competitor to coal and oil (IEA 2013). The pace at which gas use penetrates any given country's electricity generation mix depends on a large number of factors that can be fully analyzed only with detailed economic models.

Critical Question 22.

Integrated electricity and environmental modeling used in the United States and Europe helps decisionmakers better understand how lower natural gas (and oil) prices and policy drivers impact regional demand. However, such modeling is not widespread in other countries.

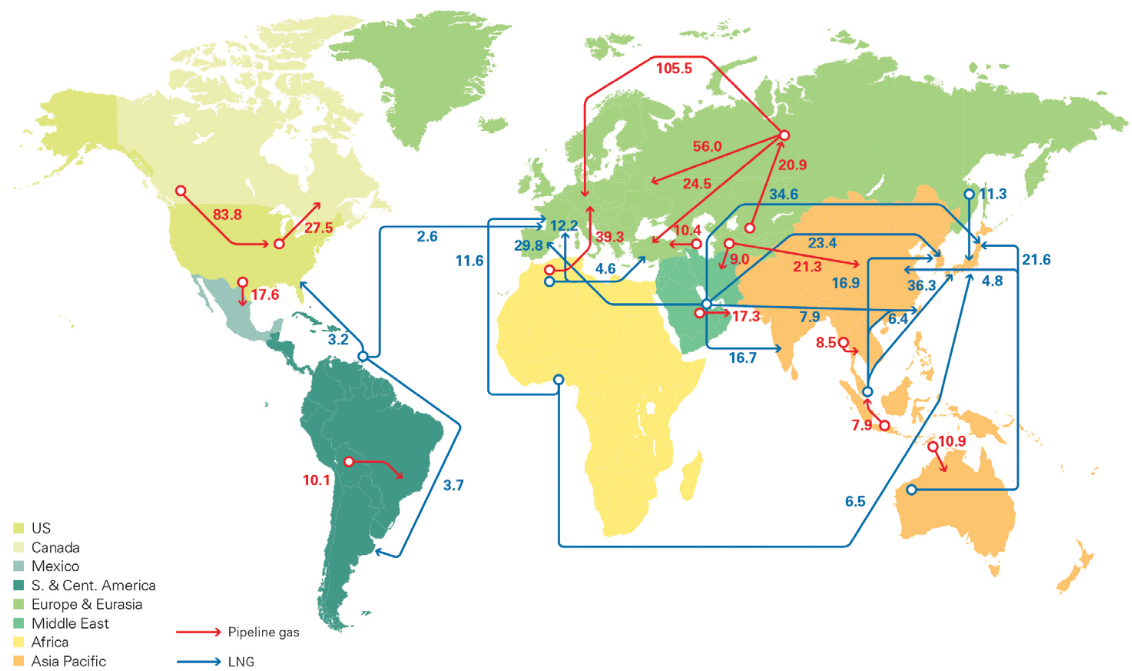
Using such models, how will lower natural gas prices and policy drivers affect regional demand in countries such as China, India, and other Asian nations?

Production and Supply

The growth of the international market for gas will depend, in part, on the rate of growth of gas demand, the location of current and future major sources of supply in relation to the demand centers, and the prices at which large volumes of international gas can be provided. OECD (the Organisation for Economic Co-operation and Development) member European countries and China have high demand but, at least for the European Union, supply potential is currently limited due to social and political barriers and potentially competitive gas imports from Russia and elsewhere. The existence of known, but yet to be exploited, shale gas resources in China, Europe, and elsewhere around the world suggests that more knowledge of the barriers to and cost of exploitation of these resources would be valuable.

Figure 6 shows international trade movements of both pipeline gas and LNG in 2012. Regions that are already suppliers of gas to the international market include Russia,

Figure 6. Natural Gas Trade Movements in 2012 (billion cubic meters)



Source: BP 2013.

the Middle East (predominantly Qatar), Australia and New Zealand, and North Africa. North America is poised to become a significant exporter, as well. This pattern of supply suggests that the foundation for a significant international market for gas exists.

Given the recent additions of major areas of supply and the potential for new and expanded entrants, a great deal of uncertainty exists with respect to the magnitudes and costs of gas available from each of the supply regions. Reducing this uncertainty can be accomplished through research directed toward a better understanding of how rapidly gas reserves will be developed in North America, China, Russia, Argentina, and Africa.

The James A. Baker III Institute for Public Policy's Energy Forum and Harvard University's Kennedy School have jointly looked at these issues, sponsoring a series of country-by-country case studies collected under the heading of "The Geopolitics of Natural Gas." The groups also sponsored a 2012 workshop in which experts from academia and industry explored various scenarios for how much new conventional and unconventional natural gas might reach global markets in the next decades (Jaffe and O'Sullivan 2012).

China is of particular interest, given the possibility that expanded gas production and consumption there could address both air quality concerns and the country's carbon-intensive energy profile. The country possesses very significant shale gas resources, but an emerging consensus is that Chinese development of these reserves will not proceed as fast as the pace seen in the United States and that these reserves are likely to be more expensive to extract (Houser and Bao 2013; Bazilian et al. 2013).

Wang, Xiaoli, and Krupnick (forthcoming) explore the factors that led to the US shale gas boom and their applicability to China, including the regulatory environment. The China Energy Fund Committee (CEFC) also released a study in late 2013 that comments on the supply situation and outlook for natural gas in China, as well as a similar regulatory comparison between the United States and China. The study suggests that shale gas will only constitute 0.6 billion cubic meters (bcm) of China's overall projected 136.2 bcm of commercial natural gas supply in 2015 (CEFC 2013). The report also notes that even though the Chinese government has encouraged more private sector (as opposed to state-owned enterprise) involvement in shale gas development, little progress has been made in that area.

Critical Question 23.

The development and expansion of the global LNG market will depend on the regional patterns of demand, new sources of supply, and the evolution of pipelines and other infrastructure.

Which countries are potential suppliers and demanders of natural gas in the international market? What barriers exist (regulatory, infrastructure, and so on) for the sustainable deployment of natural gas in trade, and how can those barriers be removed?

Transportation

Currently, gas traded internationally via pipeline still accounts for the majority of the global trade in gas (IEA 2013), and vast pipeline expansion projects are in the design and engineering stage. The Pipeline and Gas Journal's 2013 Worldwide Construction Report suggests that "116,837 miles of pipelines are planned and under construction worldwide. Of these, 83,806 represent projects in the planning worldwide design phase while 33,031 reflect various stages of construction" (Tubb 2013).

Pipelines are far more cost-effective for short and medium distance transportation of gas (less than 2,500 miles) than LNG because of LNG's liquefaction and shipping costs (Messersmith 2012). At the same time, LNG may still displace pipeline imports in the current market environments (for example, European OECD countries where pipeline gas is indexed to crude oil) due to contract differences resulting in very different delivered prices. And although the expansion of pipeline gas involves large infrastructure investments, so too does the expansion of LNG where new export and import terminals will be required.

Pricing

The price of natural gas varies dramatically across the globe. The wide disparity in regional demand and supply, combined with the high costs of transporting gas, partly gives rise to the price differentials and rapidly developing international trade in gas. However, some of the global price variation is due to the manner in which gas is priced in different markets. In addition to the three forms of pricing below, gas is priced via bilateral agreements and through administered prices. The taxonomy below is drawn from IEA's *Developing a Natural Gas Trading Hub in Asia: Obstacles and Opportunities* (Ten Kate, Varró, and Corbeau 2013).

1. Indexation to oil: gas priced via long-term contracts under which the price rises or falls over time with the price of a linked product that might be crude or refined products.

2. Spot pricing: a specific quantity of gas priced in a particular place over a very short time frame.

3. Gas-to-gas competition: gas priced via long-term contracts indexed to a regional spot market, such as at Henry Hub in the United States.

From 2005 to 2010, indexation to oil has been the dominant pricing method and is most prevalent in the Asia Pacific region (Ten Kate, Varró, and Corbeau 2013). In the past, indexation to oil has been an adequate proxy for demand and supply considerations for gas. Unfortunately, the oil market no longer reflects the same demand and supply behaviors and now gives erroneous price signals. Of the three pricing methods, spot pricing is growing the fastest (IEA 2013).

The most efficient and transparent of the pricing methods is gas-to-gas competition, where the price reflects supply and demand and can efficiently allocate the resource. This "hub" pricing brings more transparency to the international gas market and has been the topic of a great deal of speculation in the Asia Pacific region, but many do not expect an Asian hub to develop quickly.

As these pricing mechanisms evolve, are reformed, and move more rapidly to gas-to-gas competition, one could see a shrinking in global price disparities to purely reflect transportation cost differentials.

Critical Question 24.

Given the large capital investment required to export LNG, expanding the market requires pricing and other contractual arrangements between the buyer and seller that reduce investment risk. At present, pricing mechanisms and contract provisions are evolving in response to new demand and supply conditions.

How important will the very short-term-contract spot market be over the next decade? Will hub pricing be established in the Asia Pacific region? If so, when and where, and what will drive its establishment? What forms will long-term contracts take over the next decade?

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Correction: A previous version of this report cited unpublished, preliminary data related to state-level transportation and infrastructure issues, as well as property values. We regret the oversight. The references and related language have since been removed.

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