Risks and Risk Governance in Shale Gas Development: Summary of Two Workshops

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SUMMARY OF TWO WORKSHOPS

Paul C. Stern, *Rapporteur*

Board on Environmental Change and Society

Division of Behavioral and Social Sciences and Education

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Cover: Ivy Mowers (in the blue top) and Zoe Mowers (in the green top) play outside their home with views of a drilling rig and huge walls surrounding the well site in a portion of the town of Mead, Colorado, U.S., on Friday, June 6, 2014. Matthew Staver /Landov

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Acknowledgment of Reviewers

This workshop summary has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published summary as sound as possible and to ensure that the summary meets institutional standards for clarity, objectivity and responsiveness to the charge. The review comments and draft manuscript remain confidential to protect the integrity of the process. We wish to thank the following individuals for their review of this workshop summary: David H. Auston, Institute for Energy Efficiency, University of California, Santa Barbara; Alan J. Krupnick, Center for Energy Economics and Policy, Resources for the Future; Andrew G. Place, Energy and Environmental Policy, EQT Corporation, Pittsburgh, Pennsylvania; Edwin P. Przybylowicz, senior vice president and director of research, retired, Eastman Kodak Company; William H. Schlesinger, Cary Institute of Ecosystem Studies; Susan F. Tierney, Analysis Group, Boston, Massachusetts; and Rex W. Tillerson, Exxon Mobil Corporation.

Although the reviewers listed above have provided many constructive comments and suggestions, they did not see the final draft of the workshop summary before its release. The review of this summary was overseen by Robert W. Corell, senior fellow, Florida International University, and principal, Global, Environment and Technology Foundation, Grasonville, Maryland, and M. Granger Morgan, Department of Engi-

neering and Public Policy, Carnegie Mellon University. Appointed by the National Research Council they were responsible for making certain that an independent examination of this summary was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this summary rests entirely with the author and the institution.

Contents

About This Publication

This publication is a summary of two workshops, organized by a committee of the National Research Council (NRC), in which participants considered and assessed claims to advance knowledge about the levels and types of risk posed by the development of shale gas resources and about the adequacy of existing governance procedures and institutions for addressing the risks. With primary support from the National Science Foundation and additional support for participant travel and for dissemination of results from the Park Foundation and Shell Upstream America, the NRC's Board on Environmental Change and Society established a Steering Committee on Risk Management and Governance Issues in Shale Gas Development to organize the workshops, which were held on May 30-31, 2013 and August 15-16, 2013. The tasks for this activity were defined as follows:

A steering committee established by the NRC would organize two workshops to examine the range of social and decision-making issues in risk characterization and governance related to gas shale development. Central themes would include risk governance in the context of (a) risks that emerge as shale gas development expands, and (b) incomplete or declining regulatory capacity in an era of budgetary stringency. The first workshop will follow the systematic approach to risk characterization recommended in the 1996 NRC report, *Understanding Risk*, which has not yet been applied in this context. It will engage experts and practitioners in addressing the concerns of a range of interested and affected parties to identify key issues and discussing the state and limits of scientific knowl-

edge on those issues. The second workshop would engage social scientists from several research traditions to apply a variety of insights about risk management institutions to the shale gas case, while interacting with each other and with practitioners.

A designated rapporteur will write a summary of the presentations on risk issues raised in the first workshop, the risk management and governance concepts presented at the second workshop, and the discussions at both workshops. The summary might include a selection of signed papers by workshop presenters, after appropriate review. It would note the risk questions posed at the workshops for future analysis and the risk management challenges and opportunities identified, which could be considered in future national discussions about the development and implementation of the technology. It would not offer any consensus judgments or recommendations.

This report has been prepared by the workshop rapporteur as a factual summary of what occurred at the workshop. The steering committee's role was limited to planning and convening the workshop. The views contained in the report are those of individual workshop participants and do not necessarily represent the views of all workshop participants, the steering committee, or the NRC.

Introduction

Natural gas in deep shale formations, which can be developed by hydraulic fracturing and associated technologies (often collectively referred to as "fracking") is dramatically increasing production of natural gas in the United States, where significant gas deposits exist in formations that underlie many states. Shale gas production now occurs in 16 states and has increased by a factor of 8 in 5 years.[1,2] Major deposits of shale gas exist in many other countries as well. These shale gas resources and the associated production techniques are referred to as "unconventional" because the gas is trapped in the source rock and has not migrated to a "reservoir" from which it can be extracted under its own pressure by the conventional technique of drilling directly, and usually vertically, into the reservoir. Extraction requires directional (often horizontal) drilling techniques, the use of hydraulic pressure to fracture the rock and thus create pathways for the gas to flow, or a combination of both techniques (Duggan-Haas et al., 2013). Although horizontal drilling and rock-fracturing techniques have both been in use for decades, the combination of techniques, the use of new combinations of chemicals in fracturing fluids, and the expansion of shale gas extraction in scale into high-population areas and into areas where populations and governments have limited recent experience living near and regulating the industry

[1]Data from the Energy Information Administration webpage, *Shale Gas Production*. Available: http://www.eia.gov/dnav/ng/ng_prod_shalegas_s1_a.htm [April 2014].

[2]Much of the text in this introduction, particularly describing the purposes of the project, is taken from the proposal to the National Science Foundation for project support.

raise the possibility of novel consequences from this form of gas development and raise questions about the ability to manage any risks presented (see presentation by Kris Nygaard in this volume; also see Duggan-Haas et al., 2013).

Proponents of shale gas development point to several kinds of benefits, including job creation, lower gas prices, increased tax revenues to local governments, substitution of gas for dirtier-burning coal in power generation, and increased national "energy independence" (IHS Global Insight, 2011). Shale gas development has also brought increasing expression of concerns about risks, including risks to human health, environmental quality, nonenergy economic activities in shale regions, and quality of life in affected communities. Some of these potential risks are beginning to receive careful evaluation; others are not. Although the risks have neither been fully characterized yet nor all carefully analyzed, governments at all levels are making policy decisions, some of them hard to reverse, about shale gas development and/or how to manage the risks.

It is not clear that the governmental entities making these decisions have adequate knowledge of the benefits and risks or adequate resources, authority, and expertise to make and implement wise development and risk management choices. Many observers see risk management for shale gas in the United States as fragmented among an uncoordinated and organically evolving patchwork of governmental authorities that operate under a variety of laws, as well as through the activities of industrial organizations and civil society. Questions have been raised about the adequacy of risk governance because of special exemptions from federal environmental legislation that apply to this industry segment and because of the uneven and often declining capacity of state and local governmental authorities to evaluate and govern the risks in a time of budgetary stringency. In addition, new risk concerns are emerging as the technology spreads, and there are significant variations in how the technologies are used and in the associated risks across geological formations and in relation to many other ways places differ (population characteristics, built infrastructure, land use practices, policies, etc.).

Proceeding with development in this environment, with incomplete knowledge and possibly with inadequate governance capacity, has the potential to generate mistrust and continuing conflict, and as suggested in various presentations made at the two workshops, such outcomes have already occurred in various parts of the United States. Shale gas development might be headed toward a pattern of confrontation that could undermine goals for both energy production and environmental protection.

In this context, better understanding of the risks is important, and to an extent, this need is widely recognized. For example, the Shale Gas

Production Subcommittee of the Secretary of Energy's Advisory Board (2011) has emphasized the need for additional research related to the environmental impact of shale gas production. However, the language of that recommendation suggests that what is intended is technological research and development.[3] It does not suggest the need for other lines of research, including research on economic, social, and public health risks associated with the development and implementation of the technologies, on risk decision making, or on risk governance, which in some views could offer useful insights for managing the future of shale gas. In the domain of governance research, for example, some analysts have long argued that a polycentric governance approach involving different levels of government, private actors, and organizations in the nonprofit sector can be highly effective for governance of shared risks if certain institutional design principles are followed (e.g., Ostrom, 2010). Other researchers have proposed ideal processes for risk decision making that might be applied and tested in this domain (see, e.g., National Research Council, 1996, 2008). A careful examination of available evidence on the performance of such approaches to risk governance in general and in the shale gas case might help in evaluating such proposals.

These workshops were organized using the model of risk characterization developed two decades ago by the National Research Council (1996). Thus, the risk questions to be explored in the workshops were selected in part on the basis of a special effort to elicit the concerns of a broad range of "interested and affected parties": individuals and groups likely to have concerns in relation to shale gas development. The process is described in greater detail in Thomas Webler's presentation at the first workshop. As expected, the elicitation process identified several risk concerns that had not previously been given close analytic attention, including risks to ecological systems, to several public health outcomes, and to the well-being of communities directly affected by shale gas development. The elicitation also identified various concerns about the adequacy of current risk governance systems. Informed in part by this elicitation, the steering committee organized the first workshop to examine a broad range of risks that development of shale gas resources might pose to a variety of socially valued activities and entities. It focused the second workshop on the risk governance context of shale gas development, seeking to identify important governance challenges and to consider the potential of the available social institutions and of emerging polycentric governance structures to meet them.

[3]This emphasis on technological approaches to risk is also reflected in other analyses of the prospects for shale gas (e.g., National Petroleum Council, 2011).

In designing the workshops, the steering committee's objective was to assemble participants who as individuals could

- identify the range of concerns among interested parties regarding shale gas development and its governance.
- summarize available knowledge about important classes of risks and risk governance strategies that may be connected to shale gas development, particularly ones that had not previously received detailed attention.
- summarize knowledge about the capacity of existing risk management institutions to govern the risks of shale gas development.
- test the usefulness of risk governance concepts from several traditions in the social and decision sciences against the challenges of shale gas development.
- shed light on the broader problem of designing governance systems that can work in an era of declining capacity in government institutions.
- contribute to scientific understanding of the challenges of governing newly emerging risks and minimizing as-yet unidentified hazards.
- expose ideas from social science research to critique from practitioners and stakeholders who can bring experience and practicality to bear.
- test the model of risk characterization in the 1996 National Research Council report in a new domain.

The steering committee hoped that the workshops would engage, within a single, focused process, analysis of a range of environmental, health, economic, social, and other risks, not all of which are often examined together in relation to one problem. In addition, the committee hoped this process would help point the way to a risk-analytic approach aimed at more adequately informing public choices, suggest governance models that many participants believe hold promise for meeting the challenges of shale gas governance in the current era of stressed regulatory capacity, and direct the attention of the energy policy community to some fundamental social challenges—not just technological ones—that may need attention in considering policies and best practices for shale gas development. The committee also sought to ensure that the workshops would exemplify communication across diverse engineering, natural, and social scientific communities and between knowledge and action and would facilitate new scientific collaborations.

It is important to highlight two things this workshop activity did not attempt to do. First, it did not seek to be comprehensive in its cover-

age of all aspects of the potential risks or benefits associated with shale gas development, including the potential for emerging technologies to reduce risks. Rather, it sought to open discussion of a broad range of risk and risk governance issues, particularly highlighting some that had not previously received much careful analytical and empirical examination. Second, it did not seek to reach consensus on key risk issues, on promising approaches for risk governance, or on balancing risks and benefits. Rather, it sought to generate a number of promising ideas about these matters and to initiate discussion. The steering committee hoped that the issues raised in the workshops will be taken up in future efforts to understand and manage risks related to shale gas development, efforts that will examine the issues critically from multiple perspectives in the service of well-informed societal choices regarding shale gas resources.

The time frame for this activity is also worth noting. The two workshops described here were held in May and August 2013, a period when new studies and reports relevant to shale gas risks and their governance were appearing frequently. This report addresses only what the participants knew when they spoke. Work continues on many of the issues raised in the workshops; in fact, many of the participants have updated their contributions to the workshops in papers appearing in the August 5, 2014, Special Issue of *Environmental Science & Technology* (volume 48, issue 15, pp. 8287-8416) and other publications. These papers contain the authors' own views and opinions and do not represent those of the National Research Council or the workshops as a whole.

This report has been prepared by the workshop rapporteur as a factual summary of what occurred at the workshop. It also includes the rapporteur's summaries, based on the workshops, of some risk questions that may need future analysis (at the end of the summary of the first workshop) and of important challenges, opportunities, and issues that may require future research for shale gas risk management (at the end of the summary of the second workshop). The steering committee's role was limited to planning and convening the workshop. The views contained in the report are those of individual workshop participants. The two summaries mentioned above are the rapporteur's best effort to summarize those views. None of the views expressed represent the views of all workshop participants, the steering committee, or the National Research Council.[4]

[4]Video recordings of the presentations, comments, and discussion sessions at the workshops, as well as copies of the presenters' slides and abstracts of their presentations, can be found at http://sites.nationalacademies.org/DBASSE/BECS/CurrentProjects/DBASSE_069201 [July 2014].

Workshop 1

Risks of Unconventional Shale Gas Development

The purpose of this workshop, held May 30-31, 2013, was to take a broad look at the risks, actualized or potential, associated with the development of shale gas resources.[1] To identify the risks to be examined, the committee organizing the workshop considered both existing accounts of these risks and the public discourse and controversy about shale gas development. It also conducted its own elicitation of concerns about such risks by inviting input from a variety of individuals and groups that may have an interest in or a concern about shale gas development. Because it was not feasible to go into detail on all the types of risks that have raised concern, the organizing committee had to be selective and had to group some types of concerns into broader categories for the purpose of inviting presentations for the workshop.

The National Research Council (NRC) project director for the two workshops, Paul C. Stern, opened the workshop by describing its purpose and thanking the sponsors. Mitchell Small, chair of the steering committee for the workshops, distinguished the purposes of the two workshops. He described this initial workshop as being about characterizing the risks and the second as being about options for risk management and governance. He quoted the charge to the committee as follows: "This project will point the way to a risk-analytic approach aimed at more adequately informing

[1]The agenda for this workshop, the speakers' abstracts and slide presentations (in PDF format), and video archives of the presentations and discussions are available at: http://sites.nationalacademies.org/DBASSE/BECS/CurrentProjects/DBASSE_069201 [July 2014].

public choices, will suggest governance models that hold promise for meeting the challenges of environmental protection in an era of declining regulatory capacity, and will direct attention of the energy policy community to the need to include fundamental social challenges—not just technological ones—in the development of policies and best practices."

Small spoke briefly about the widespread presence of shale gas globally, noting that the U.S. Energy Information Administration now projects that by 2040, shale gas will account for about half of U.S. natural gas production—a considerably higher projection than was made 15 years ago. The expectation also is for well densities of four-eight wells or more per square mile in areas where development occurs. The workshop will be looking at the implications of this density of development for various kinds of risks, he said.

He summarized the agenda for the workshop and said that the presentations would review the literature on the risk topic being covered; characterize the risks, including who is exposed, the routes of exposure, and the endpoints; discuss the methods used for estimating the risk; summarize evidence on the magnitude and attribution of the risk; and identify the key uncertainties and the kinds of studies needed to reduce them. He outlined the procedures for the workshop and encouraged all participants to maintain a tone of shared search for understanding, even though the topic is increasingly controversial.

CONCERNS ABOUT SHALE GAS RISKS: RESULTS FROM A PUBLIC ELICITATION

Presentation by Thomas Webler, Social and Environmental Research Institute

Webler, a researcher who specializes in collaborative processes for environmental decision making that engage experts with interested and affected parties, presented work he conducted at the request of the organizing committee. His collaborators on this work were Andrei L. Israel of Pennsylvania State University, Gabrielle Wong-Parodi of Carnegie Mellon University, and Paul C. Stern of the NRC. Webler began by characterizing shale gas extraction, with its combination of hydraulic fracturing and horizontal drilling, as involving an emerging technology that presents multiple types of risk. Citing the *Understanding Risk* report (National Research Council, 1996), he noted that to understand a risk issue, it is first necessary to characterize the risks, beginning by identifying the risk concerns of the interested and affected parties. He defined these parties as elements of the public that had educated themselves on the technology and that might be acutely aware of potential risks.

Webler noted that there are multiple ways to identify risk concerns. Resources for the Future (RFF) has conducted a study of experts' concerns, reported later in the workshop, and Yale University recently released results of a survey of the general public. The results reported by Webler came from a different approach: seeking input from the interested and affected parties. Limited time and budget resulted in the use of an Internet-based survey that began with a search of Facebook and the Internet for groups believed likely to be concerned with shale gas development: 24 local antishale gas development groups, 17 regulatory agencies, 7 gas company groups, 6 groups in the consumer gas industry, and several additional groups in the finance industry, the energy media, or the renewable energy industry. Contact persons in these groups were identified and invited to send the elicitation instrument to anyone they thought would be interested.

The instrument asked two open-ended questions about shale gas concerns and topics that the respondent wanted to know more about. It also asked a few questions to determine the respondents' states of residence and their connections, if any, to the industry. Overall, 372 responses were received, with a very wide range in format, tone, and level of detail; 40 percent of responses came from New York, 16 percent came from Ohio, and fewer were from other states. The great majority of respondents (76%) were from the four Marcellus shale states of New York, Ohio, Pennsylvania, and West Virginia, despite the effort to get respondents nationwide. Just over half (56%) of the respondents were members of groups opposing shale gas development; only small numbers were from members of groups supporting the industry or from employees of the industry.

Webler characterized the responses as falling into the five broad categories identified by Kasperson and colleagues (1988): hazards (e.g., fracking fluids), hazardous events (e.g., spills), the consequences of such events (e.g., ground water contamination), precursors (e.g., poor regulations), and risk amplifiers (e.g., obfuscation of information). The responses were examined using the constant comparison method of Glaser and Strauss (1967) for analyzing qualitative data: the responses were divided into codable data segments (2,567 in all), after which the three coders met as a group to develop a list of codes (which numbered 131) and then coded the data segments.

Although the sample was not representative of a specific population, the research group considers it meaningful in the sense that concerns that are frequently mentioned by interested and affected parties are important to investigate. It is also possible, of course, that concerns that are not mentioned frequently may also be important to investigate. The slide presentation summarized the frequencies of mention of concerns in each

of the five categories; consequences of hazardous events were the most frequently mentioned category.

Webler summarized the 131 coded concerns as falling under 9 themes:

1. quality-of-life concerns (mentioned by 25% of respondents)—loss of rural character, crime, loss of beauty, community conflict;
2. economic impacts (18%)—loss of property value, disruption to existing businesses;
3. impacts distant from well sites (24%)—earthquakes, injection wells, wastewater treatment and disposal;
4. climate change (17%)—including effects on renewable energy and overall energy consumption;
5. quality and availability of information (18%)—insufficient disclosure, obfuscation of information;
6. regulations and regulatory capture (46%)—poor regulations, flawed or biased science, inadequate oversight, exemptions from laws;
7. ethics and environmental justice (10%)—procedural and distributive injustice concerns;
8. wasted water resources (13%); and
9. ecosystem and domestic animal impacts (22%)—such as effects on wildlife and domestic animals and habitat fragmentation.[2]

Webler concluded by saying that the respondents, some of whom had given a lot of thought to the issues, had raised a wide variety of concerns, some of which have already received careful analytical attention while others, such as quality-of-life and justice concerns, have not. He noted that the concerns go beyond what has been called NIMBY-ism;[3] they include concerns about climate, ecosystems, and impacts distant from well sites. Also, many respondents expressed lack of trust in existing institutions to do what is needed to reduce risks. He noted some overlap between the concerns raised by these respondents and the expert concerns in the RFF study (e.g., concerns with air and water quality) but also suggested that the overlap may not be complete. Webler said that all these approaches may contribute useful information about concerns related to shale gas development.

[2]Habitat fragmentation, as the term is used here, refers to situations in which the preferred environment of a population of organisms is physically divided, for example, by land clearing or road construction, so that the population itself becomes divided.

[3]"NIMBY" stands for "not in my backyard" and refers to expressions of concerns about having undesirable activity close to one's home, as opposed to concerns about the same activity at any location.

Questions and Discussion

Several issues arose in the discussion after the presentation. One concerned method that might be used to "take the pulse" of stakeholders, including content analysis of local and national media, examination of social media, and the use of semistructured interviews to explore the ways that opponents and proponents of shale gas development think about the issues. There were also related questions about whether sampling of stakeholders was representative. Alan Krupnick (RFF) said there were great contrasts between this study and the RFF study, which he thought might be due to the fact that RFF tried to get wide representation from academics, government, industry, and nongovernmental organizations (NGOs). Another participant suggested that the use of Facebook to get respondents might have overweighted the sample toward the Northeast.

A third issue was whether concerns differed in different states. Krupnick noted that in RFF's 1,500-person public survey, which was still being analyzed at the time of the workshop,[4] there appear to be both similarities and differences in stakeholder concerns across states. For example, respondents in Pennsylvania and Texas seem to have similar attitudes about effects on ground water, but surface water is more of a concern in Texas, and habitat fragmentation is a big issue in Pennsylvania. Webler noted that in the elicitation study, there were some state-specific concerns, such as with impacts on the wine and tourism industries in New York and with wastewater issues in Ohio. A fourth issue was the possibility of systematic differences between concerns of people in places that have had and have not yet had direct experience with the industry and shale gas technologies.

One participant asked about concerns among people who believed that their own health had been harmed by shale gas development. Andrei Israel, one of Webler's collaborators, said that respondents to this elicitation had expressed concerns about health generally, rather than specifically about their own health.

OPERATIONAL RISK ISSUES IN SHALE GAS DEVELOPMENT

Presentation by Kris J. Nygaard, ExxonMobil Production Company

Nygaard, an engineer and senior stimulation consultant with the ExxonMobil Production Company, focused his comments on four key

[4]A brief report of the results of the survey is now available at http://www.rff.org/RFF/Documents/RFF-Resources-185_Feature-Krupnick,%20Siikamaki.pdf [May 2014].

topics: responsible operations, well construction and design, operational integrity, and potential impacts.

Responsible operations. Nygaard said that engineers use the term "fracturing" to refer to one part of a larger process to which the public typically applies that term. The larger process includes drilling, fracturing, extraction, and completion, and it occurs over a longer period of time than fracturing in the engineering sense. He said the keys to success in responsible operations are to identify the risks, the possible consequences, and the probabilities of their occurrence; to account for uncertainties (for example, in the subsurface conditions); to collaborate with stakeholders and regulators to share information and develop a common frame of reference; and to generate opportunities for meeting energy demand, producing jobs and revenue, and reducing environmental emissions.

Nygaard noted that the industry has been doing horizontal drilling for 20 years. What is new, he said, is development at large-scale and in high-population areas, which brings increasing public notice to the process. The American Petroleum Institute has published several documents showing recommended practices for well construction and operation; if these are followed, Nygaard said, wells can be operated safely. The challenge occurs when equipment is used outside contingent performance limits or if procedures are not followed. Regulations are critical, and local and state regulation are especially so because local geology varies, Nygaard continued. Strong company practices and policies are also necessary for risk management, including high standards and management accountability for adhering to regulations, the use of good engineering judgment, and employee training.

Well construction and design. These processes are dependent on local geology and local gas or oil resources. Water utilization and disposal also vary greatly by local geology. For these reasons, Nygaard stressed that local regulation is important. He noted that the surface footprint of wells is relatively small: a pad of about 3-5 acres on the surface allows access to 1-2 square miles of underground formations. He described the volumes of materials required for a typical well: about 8 Olympic-size swimming pools of water,[5] about 20 rail cars of proppant materials (mainly sand to

[5]According to the Fédération International de Natation facilities rules, a swimming pool for the Olympic Games is 50 meters long between the touch panels, 25 meters wide, and a minimum of 2 meters deep (3 meters recommended) (see http://www.fina.org/H2O/docs/rules/facilities_20132017.pdf [July 2014]). Assuming a 2-meter depth, one such pool would contain about 2,500 cubic meters of water. Eight such pools would contain 20,000 cubic meters (20 million liters) of water, which is equal to about 706,000 cubic feet or 5.3 million gallons.

open small cracks and enable production), about 6 truckloads of chemical additives, and about 20-30 truckloads of stimulation equipment. He said that in well construction, the industry's primary goal is to protect ground water resources. This is done by using multiple barriers to mitigate the risk (for example, multiple cement casings), and by designing for well completion at the start of the process. The industry follows robust mechanical engineering design approaches for pressure vessels in designing wells and custom-designs every well to fit the resources and local regulations. The industry, Nygaard continued, also strives to minimize the use of chemicals as much as possible, consistent with achieving a project's technical objectives. He said that chemicals are used only as needed to mitigate corrosion and address other engineering issues, such as reducing friction. Extensive diagnostics are used to check on the fractures and the flowback.

Operational integrity. Nygaard said that the industry uses a range of approaches for monitoring casing and cement placement in a well as it implements treatments. He said that monitoring of a treatment may take 4-5 hours of continuous monitoring, with a commitment to shut down a well immediately if anomalous behavior is noticed.

Potential impacts. Nygaard referred to a recent study by George King (2012), which examined the probabilities and consequences of 21 different possible events and assessed the risk levels for each. Nygaard emphasized that potential ground water contamination is an issue in the public eye. He reported on one study (Fisher and Warpinski, 2012) that indicated that the heights of the tops of fractures in microseismic events were well below the depths of ground water in various shale gas plays and a second study that examined 396 documented incidents in Texas and Ohio and found a great decline in frequency of microseismic events over time.[6] Nygaard noted that pit lining contributed to a large number of these events, indicating the importance of monitoring.

Induced seismicity has also been raised as an issue, Nygaard said. This can be triggered by changes in stress states near faults, he explained, adding that industrial operations of many kinds, not only shale gas extraction, can run this risk. He cited an NRC study (National Research Council, 2013) as having evaluated these risks and found low risk, though he noted that there can be unique high-risk cases.

Nygaard summarized his presentation by saying that each shale play is unique and requires unique solutions; that reliable and safe development can be achieved with collaborative engagement between the public,

[6]See Kell (2011).

regulators, and operating companies; that reasonable, locally specific regulations need to be combined with a responsible operations philosophy and effective risk management practices; and that transparency and reasonable regulations can enable natural gas to be economically developed in an environmentally responsible manner.

Discussant Comments, Mark Zoback, Stanford University

Zoback, who serves as Benjamin M. Page professor in earth sciences and senior fellow at the Precourt Institute for Energy at Stanford University, presented slides addressing multiple topics raised by the Secretary of Energy Advisory Board on which he served. His brief comments, however, focused on the earthquake issue (his primary area of expertise). He said that there has been an unusual amount of seismicity in the United States in the past few years, including in areas where shale gas operations are ongoing. Triggered seismicity has long been known to be a potential consequence of underground injection of water. He explained that injection of fluids reduces the coefficient of friction that keeps plates from sliding across each other, so that the timing of eventual earthquakes is advanced. He said that this effect of water injection is indeed something worth worrying about and that impoundment in reservoirs can also induce seismicity. The issue is to decide when it is worth worrying about induced seismicity from particular activities. It is possible to map the locations where induced seismicity is most likely to occur; when injection into those areas stops, the induced seismicity stops. Thus, he continued, there is a need to monitor potential seismicity, manage the pressures, and act accordingly.

Zoback said we know how to do this: "it is not rocket science." He summarized the NRC report on induced seismicity (National Research Council, 2013) as having three main messages: (1) the very small seismic events associated with the fracturing process itself pose essentially no risk to the public; (2) the risks associated with wastewater injection pose a larger, but still low risk, which can be reduced by site characterizations and proactive planning; and (3) the potential for induced seismicity is much larger with carbon capture and storage[7] than with shale gas development.

[7]"Carbon capture and storage" refers to processes to remove carbon dioxide from the air, chemically combine it into a nongaseous form such as a carbonate, and then inject the carbonate underground or otherwise store it indefinitely.

Discussant Comments, Meagan Mauter, Carnegie Mellon University

Mauter, who serves on the faculty in Chemical Engineering and Engineering and Public Policy at Carnegie Mellon University and conducts research on resource efficiency in water and energy systems, cited Webler's presentation to support her point that the risks discussed in Nygaard's presentation are not the only ones that need to be characterized. She noted that the probability and consequences of a risk event occurring are not the only important dimensions of risk, citing the work of Slovic and colleagues (e.g., Fischhoff et al., 1978; Slovic, 1987) on perceptions of risk, which found that perceived magnitude of risk is strongly affected by the degree to which a risk is dreaded and unknown. She suggested that unplanned fluid migration is a risk that seems uncontrollable, in contrast to risks like truck accidents, which may have higher consequences but are not so dreaded or unknown, so may not be perceived as being as serious.

Mauter reported on some as-yet unpublished research on liquid waste transport in the Marcellus shale formation in Pennsylvania. This research found that the mean transport distance for flowback water was 113 miles, with transport of water for shale gas development accounting for about 0.1 percent of all truck traffic in Pennsylvania in 2011. This transport traffic has associated risks including diesel emissions, accidents, and others. The research found, she continued, that the percentage of waste a company reuses was the strongest predictor of length of waste transport and that most other company characteristics were not predictive. In this research, company attributes and experience did affect how waste was managed: Larger companies reused less waste, and companies that drilled more wells in 2011 or that had longer experience in the Marcellus shale region reused more of the waste. Companies that had more wells in a cluster reused more of their waste. Mauter added that company attributes do not do a good job of explaining frequency of violations of wastewater regulations.

Questions and Discussion

Participants' questions and comments to the presenters raised multiple issues, which are summarized by the rapporteur below under the headings of injection of wastewater, green completions, industry communication about risks, safety culture issues, air emissions, water retention pits at well sites, and long-term issues with flowback.

Injection of wastewater. In response to a question about whether injection of wastewater into deeper formations is a viable idea, Nygaard said that in a number of shale plays it is feasible to recycle the water, but in other areas, where local water is not of sufficient quality for fracturing, disposal

is needed. In those cases, operators need to find the right place for disposal. Zoback noted that there are far more injection wells in Texas than in Pennsylvania because there is a large saline formation under much of the shale area that allows for recycling the water. He emphasized, though, the need to match practices to what nature makes possible. Even where injection wells have operated safely for decades, it is possible to go beyond the capacity of the formations to accept additional wastewater.

Green completions. In response to a question, Nygaard said that flowback equipment is designed to allow for separation of liquids, solids, and gases, so that, depending on local conditions, it is sometimes possible to earn money from the separated components. He said that green completion increases cost, but not to the point of doubling it.

Industry communication about risks. Bernard Goldstein, a professor at the University of Pittsburgh Schools of the Health Sciences, proposed that it is the industry's responsibility to make sure the public understands the risks. In his search of the records in Pennsylvania on water issues, he found that companies and the state government mentioned that there was no water shortage problem as sometimes arises in the West, but they never mentioned that underground injection of wastewater is not feasible in Pennsylvania, as it is in Texas. He also said that people in Pennsylvania were commonly told that fracking was a short-term proposition lasting about 2 weeks, but they were not told that it is normal to have eight consecutive frackings. Goldstein cited George King [the petroleum engineer whose study Nygaard had cited] as having said that industry may have gotten it wrong by letting people think that fracking was just the release of gas from underground and not considering that public concern has been about whether ground water will be contaminated.

Nygaard said that industry has found that the more information it provides in community engagement, the better—whether in Texas, in the Marcellus formation, or internationally. Eight years ago, when the Barnett shale play was opening up, industry had not yet learned much about water management or about communication. He said that this is a developing process, in which industry is learning about the need to provide the public with much more detailed information.

Another participant asked if industry could be more aggressive in providing background information about water and air issues in advance of development, noting that governments lack the ability to collect all this information. Nygaard replied that transparency across groups is important and that doing more to be transparent is better.

In response to a question about public availability of data about toxic chemical exposure, Nygaard said that in the past 2-3 years, industry has

made significant strides in public information. He cited FracFocus as making much detailed information available and said that in selecting fracturing chemicals, the company looks for those that do best at moderating environmental exposures while meeting the requirements for fracturing.

Safety culture issues. A participant asked about managing the risks of unexpected events, especially when many different people and companies are involved on a well pad and face economic pressures. He offered an example of a driller who unexpectedly came upon an abandoned coal mine shaft into which the cement for the well lining kept flowing freely. He asked how operators inculcate conservative behavior [with respect to safety] among employees making many moment-by-moment decisions. In his reply, Nygaard emphasized two main points: corporate culture and a regulatory environment that is reviewing and assessing situations. Key to corporate culture in his company, he said, is the expectation that we will operate safely and the understanding that any release must result in notifying management. He said that his company has a culture of safety and empowerment: any employee can shut down the operation if something may be unsafe.

Zoback added that safety culture is fundamentally a management problem. He noted some similarities with offshore oil drilling. In working on the National Academy of Engineering's study of the Deepwater Horizon accident, he found that a strong safety culture is more effective than just having operators follow regulations. He cited the American Petroleum Institute's recommended practices, described by King (2012), which call for multiple barriers, as illustrating the best way to achieve a goal such as protecting surface aquifers. He said that regulations need to focus on the right issues: setting and achieving an environmental objective, rather than specifying a set rule to be followed.

In response to a question about how safe practices and the American Petroleum Institute recommendations achieve accountability for service contractors to well owners, Nygaard said that safety culture has to come from the chief executive officer on down and has to empower all the employees. He also said that the owner of the well is responsible for the service providers; his company evaluates contractors' safety performance and environmental compliance, trains and orients them, asks whether their staff is capable of delivering his company's needs, and lets crews go when not comfortable with their performance.

Air emissions. In response to a question, Nygaard said that although his presentation did not address them, air emissions are also of concern in operations. He noted, though, that all emissions across the shale gas life cycle need to be compared with those from other energy sources. Zoback

added that proper well design and construction is the first line of defense for air emissons as well as for water contamination.

Water retention pits at well sites. In response to a request for more information about how these pits are used, Nygaard distinguished pits used to store fresh water for fracturing from those for storing flowback water. He said that in designing such pits, his company considers berms and embankments, linings, sizing pits to accommodate expected rainfall, and avoiding floodplains. It then uses engineering design.

Long-term issues with flowback. An Internet participant asked what the industry is doing to address long-term risks from flowback after the lifespan of the well, especially with corrodible metals and concrete, and also about the liability situation after wells have exceeded their productive life. Nygaard said he was unable to comment on liability, but that in well construction, his company selects materials that will resist corrosion from the fracturing fluids and the flowback and designs wells for their intended lifetimes. Once the productive life is ended, he said the company returns to apply plug and abandonment procedures as established by state regulations to avoid long-term exposure.

RISKS OF SHALE GAS EXPLORATION AND HYDRAULIC FRACTURING TO WATER RESOURCES IN THE UNITED STATES

Presentation by Avner Vengosh, Duke University

Vengosh is professor of geochemistry and water quality and chair of the Water and Air Resources Program at the Nicholas School of Environment at Duke University; his research focuses on connections between energy and water quality. He presented work on which he collaborated with Robert Jackson, Nathaniel Warner, and Thomas H. Darrah, all of Duke University. He began by emphasizing that there are many gaps between what is known and what stakeholders want to know about the effects of shale gas development on water resources. His presentation, he said, would discuss only a few of the issues.

Stray gas contamination, such as the appearance of methane in drinking water wells near shale gas development, can cause fire and explosion hazards. Although direct health effects have not been found from drinking high-methane water, Vengosh, said, the presence of methane in water can cause water wells to be shut down, thus depriving users of their water supplies. He added that one study (not cited) also indicated that methane in water can decrease property values. Vengosh said that although some

studies suggest that methane in shale gas areas is a naturally occurring phenomenon (e.g., Molofsky et al., 2013), other studies that look closely at the chemical composition of the methane (e.g., Osborn et al., 2011) indicate that it is possible to distinguish different sources of methane in well water. The study by Osborn and colleagues found that water wells less than 1 km from active shale gas wells had a higher probability of having methane levels above the action levels defined by the U.S. Department of the Interior, implying that there is potential hazard to households using those wells. Newer data from Vengosh's Duke University group reinforces these findings, suggesting that stray gas from shale gas wells was the cause of observed high methane levels in nearby drinking water wells. Several mechanisms could cause this contamination, but the most likely ones, according to Vengosh, include inadequate well integrity, improper cementing of wells, and improper well design that allows gas to escape along the well annulus. He emphasized the limitations of available knowledge. Although the existing studies are detailed, they cover only limited areas. A new study by his group and other coauthors (Warner et al., 2013) did not find a correlation between distance from gas wells and methane concentrations in areas of extensive shale gas exploration in Arkansas. What was found in the Marcellus shale may not apply to the Fayetteville shale, Vengosh concluded, so there is a need to look at every basin.

Surface water contamination can arise from spills of fluids, from normal well operations, and from disposal of wastewater, Vengosh said, adding that the risks likely vary across shale plays. In the Marcellus shale, the consensus view is that 10-20 million liters of water are needed for an average well and that wastewater volume averages 5.2 million liters, for a total of 3.1 billion liters across the Marcellus operations in 2011 (Lutz et al., 2013)—about four times the volume from conventional oil and gas production. Wastewater in the Marcellus formation has high salinity and bromide levels that could contaminate downstream water, toxic elements such as barium and arsenic, naturally occurring radioactive materials, and various organic compounds. The salinity in the flowback water sometimes poses a greater hazard than the toxic contents.

Vengosh explained that the wastewater has been treated at municipal treatment facilities or private industrial brine treatment facilities, disposed via underground injection, recycled for additional use in fracking (the use of about 70% of Marcellus wastewater in 2011), or spread on roads for ice control (a use that is still allowed in West Virginia but not in Pennsylvania). He noted that each treatment approach has risks: Treatment in municipal plants decreases the effectiveness of those plants for treating domestic wastewater; treatment in brine facilities is inadequate for handling halogens or radioactive materials. Deep injection has seis-

micity risks and is not possible in all locations. Recycling is the desired solution, but high levels of barium and sulfates could shut down well operations. Wastewater treatment does not remove all the contaminants; it leaves high salinity and bromide levels, so that treatment effluent may have several times the upstream levels of bromide for as far as several kilometers downstream. Such effluent could increase the formation of carcinogenic disinfection by-products when the water is chlorinated as a source of drinking water by communities downstream. For these reasons, Vengosh said, zero discharge of any effluent should be a goal for shale gas operations.

Long-term effects are of four main types. Long-term effects on water availability can be an issue in some places, Vengosh said. In the Marcellus shale, water use is 40-60 million cubic meters per year; in Oklahoma, 16 million cubic meters, which amounts to about 1 percent of statewide fresh water use. In the Barnett shale, 30 million cubic meters of water are used annually, which is equivalent to 7 percent of all water use in Dallas (Nicot and Scanlon, 2012). A prediction that Vengosh used for water use in shale gas extraction nationally is 150 million cubic meters per year, which he said is far less than is used for hydropower. However, in water-scarce areas in the West, such as Texas, where some counties have only ground water as a source for fresh water, he thought that competition for that water could become an issue.

A second long-term issue concerns connectivity between deep and shallow aquifers. The industry emphasizes a vertical distance of 3-4 km between ground water and the water used in drilling, Vengosh said, but even though the geological systems have low permeability, this may not be sufficient. More research is needed to quantify the connectivity between deep and shallow aquifers. Myers (2012) offered an initial estimate that contaminants will arrive in deep aquifers in about 10 years, though Vengosh said that there is a lot of debate about this estimate. Osborn and colleagues (2011) found that water wells in Pennsylvania valleys have a distinctive geochemical and isotopic fingerprint, with very high salinity similar to that of the Marcellus brine, but distinguishable with sophisticated isotopic fingerprinting of strontium concentrations. The study found that similarly saline water was found in the 1980s in the system, so the presence of saline water need not imply current contamination. However, Vengosh suggested, considering that this is an area with a high rate of water recharge, saline water would have been flushed away by now, indicating that there must be some continuous connection, possibly from shale gas development.

A third long-term issue, suggested by Harrison (1985), is possible ground water contamination from improper seals in gas wells. Gas and

brine might enter the annulus of improperly designed wells and be released into the surrounding formation, particularly in places where water and gas could flow from abandoned and improperly sealed gas wells into conventional water wells. There are areas of very high well density in southwestern Pennsylvania, which should be considered high-risk areas. Well density is much lower in northeastern Pennsylvania.

A fourth issue discussed by Vengosh concerns certain contaminants, such as radium, that remain in the environment for a very long time after they appear. After wastewater is disposed of, the amount of radium in the downstream sediment may increase over time because of the long half-life of radium. Tools are available to identify the sources of radium in water, and locations with high radium concentrations have been mapped (Lutz et al., 2013).

Vengosh concluded by reemphasizing that the scientific understanding of the risks to water sources from shale gas extraction is still in a very early phase and that decisions about risk are currently based on very limited data.

Discussant Comments, Jean-Philippe Nicot, University of Texas

Nicot is a civil engineer and a research scientist at the Bureau of Economic Geology at the Jackson School of Geosciences at the University of Texas; his research interests include modeling of contaminant transport. He spoke first on the issue of methane in water wells, emphasizing the point made by Molofsky and colleagues (2013) that gas in shallow aquifers does not necessarily indicate contamination. He said that it is important to have baseline data on wells and that more drilling companies are now collecting such data, which will give a better idea of the sources of methane in well water. He also noted that there is extreme variation in methane concentrations in water at a single point and reiterated that it is important not to generalize across shale plays about either methane or the appearance of radioactive materials.

Regarding water use, Nicot said that in Texas, the industry uses about 100,000 acre-feet/year of the 15 million acre-feet available overall (0.67%) and that in Colorado, industry use is also a very small fraction of all available water. Although water levels are dropping, this appears to be mainly a result of drought and increased water use for other purposes. He referred to a new report from the U.S. Geological Survey, not further identified, which shows that water levels are dropping at the same rate across a geologic region, regardless of whether shale gas is being developed in parts of that region. Nicot said that when a single water well goes dry, this does not necessarily indicate depletion of the whole aquifer; the

key question is whether there is enough water at, for instance, the county level to support the multiple uses, including fracking.

On the issue of fluids migrating along faults, Nicot said that well operators normally don't drill at geologic faults, which lowers the risk of fluid migration. He agreed with Vengosh that brine does move across geological levels, but said it is an open question how fast it happens.

Questions and Discussion

Several issues were discussed in response to questions and comments from the participants. The rapporteur has summarized these under headings of regional planning, monitoring, and other issues.

Regional planning. Warner North, principal of Northworks, Inc., said that in the Marcellus shale, the release of bromides, radon, and other contaminants into rivers is a major problem. He suggested that there ought to be a carefully planned regional system for disposing of the wastewater, rather than doing this well by well. Furthermore, regional cooperation might be appropriate in the arid West, where the issue is moving large amounts of water. Nicot responded that in West Texas, where there is not much fresh water, the state has been getting good information on aquifers and the industry is increasingly using brackish water and asking the state to study brackish aquifers as possible water supplies. Vengosh added that he was unaware of any such cooperative efforts in the Marcellus basin.

Monitoring. Workshop chair Mitchell Small said that the U.S. Environmental Protection Agency (EPA) has an information collection rule for water treatment plants and wondered if a similar program of industry monitoring with regulatory oversight existed for shale gas, or if not, whether it would be helpful. Vengosh replied that he was unaware of any systematic monitoring program to produce public domain information before and during shale gas extraction operations. He said the industry has a lot of information, but it is not all publicly available; despite research efforts to monitor in particular places, there is no overall effort, which is why the "big picture" is lacking. Vengosh advocated a general public monitoring system using the best available analytical tools to delineate sources of contaminants in the subsurface. He said it may be too late to do this where drilling is already occurring, but it could certainly be done in new shale plays, such as the Monterey formation in California. Zoback commented that the Secretary of Energy Advisory Board on which he served called for a process of continuous improvement in the science, but the government has failed to follow through on that recommendation. He agreed about the need to collect more data.

Other issues. In response to Zoback's suggestion that fracking will reduce the core pressure in gas wells so that fluids should be attracted downward into the wells rather than upward toward aquifers, Vengosh said that he had not seen a study that has tried to simulate that situation in real formations. He said that to answer this sort of question would require drilling research boreholes and monitoring pressures and flows.

There was further discussion of the possibility that thermogenic gas observed in water wells could have come from shallower shales than those being drilled for gas. Vengosh said that Molofsky's research was based on very few observations. He noted that contamination from an intermediate level could come from a well casing failure rather than a natural process. Vengosh said that the studies by Osborn and colleagues (2011) and by Molofsky used different underlying assumptions. Robert Jackson added that there are many ways to tell different sources of gas apart and said that in the research by the Duke University team (to which he and Vengosh belong), there was evidence of both Marcellus gas and gas migration from shallower shales in the water wells investigated.

An Internet questioner asked about losses of water that is injected deep underground and does not return to the system (that is, the Earth's hydrosphere). Nicot responded that he did not see this as a water loss issue because the oceans provide a huge reserve of water and because burning the extracted gas produces more water vapor than is lost by subsurface injection. He also said that evaporation of water used for irrigation and power plants takes much more fresh water than the shale gas industry does. Vengosh concurred, saying that even though shale gas extraction needs a lot of water, it is a small demand on freshwater resources relative to other energy-related uses.

AIR IMPACTS OF GAS SHALE EXTRACTION AND DISTRIBUTION

Presentation by Christopher W. Moore, Desert Research Institute

Moore is an assistant research professor in the Division of Atmospheric Sciences at the Desert Research Institute, where his research focuses on the cycling of atmospheric pollutants. His presentation examined air emissions that can occur at each stage of the shale gas life cycle, summarized available data, and addressed areas where data may be lacking. He emphasized that hydraulic fracturing is only one part of the life cycle of shale gas development, which includes the phases of well development, production, distribution and storage, use, and end-of-life stage (e.g., well closure) (Branosky et al., 2012). The data on air emissions are almost entirely from the first three stages of the life cycle, he said.

Emissions of concern, Moore continued, include methane and ethane; benzene, toluene, ethylbenzene, and xylenes; hydrogen sulfide; ozone precursors; particulate matter; and silica. All these can have respiratory effects; benzene is a carcinogen. Modeling studies suggest that shale gas will have greenhouse gas implications similar to those of coal and conventional gas over 20- and 100-year timelines, but there has been a lack of direct measurements to support such expectations, Moore said, and estimates of emissions such as EPA's (e.g., U.S. Environmental Protection Agency, 2013) have been volatile. As an example, he said EPA's estimate of 2010 methane emissions from all gas operations dropped by 33 percent between 2012 and 2013. Getting accurate estimates is important because, according to Moore, natural gas extraction is the largest U.S. source of methane. Moore added that methane emissions from gas extraction processes appear to come mostly in the well development phase.

In the well development phase, he continued, the major air emissions are from vehicle traffic, which produces emissions from diesel fuel, and coarse particulate matter from road development. In the drilling and fracturing phase, 1 to 5 million gallons of water are hauled per well, bringing diesel emissions from trucks, and there are also emissions of fracking fluid and sand, along with releases of volatile organic compounds and silica. Particulate matter, hydrogen sulfide, and methane can also be released during drilling, Moore said. During well completion, flowback water is removed from the well bore and there is often venting and flaring, which he noted can release methane, hydrogen sulfide, and volatile organic hydrocarbons. Moore also noted that the well completion process has begun to be regulated more frequently.

Moore briefly discussed a few case studies that illustrate the state of empirical knowledge. In one, McKenzie and colleagues (2012) sampled around well completion activities at four well pads in Garfield County, Colorado. They evaluated risks to residents within and beyond half a mile from the wells and found increased health risks for residents living nearer to well sites. Moore considered this a good study, but one that only scratches the surface because it needs validation in other areas. An air quality study at eight sites in Fort Worth, Texas, did not find any air impacts related to gas drilling, concluding that a 600-foot setback adequately protected the public.[8]

In the production stage, the main emissions are of methane and volatile organic hydrocarbons from leaking valves and from diesel-powered compressor stations, Moore said. A study in Wise County, Texas (Zielinska et al., 2011) characterized emissions from gas facilities based on monitoring downwind of production areas and concluded that there is an expo-

[8]See City of Fort Worth (2011).

nential decrease with distance of concentrations downwind of condensate tanks. The study could not determine whether these emissions were significantly higher than normal emissions sources in the area, except that a significant level of benzene was generated. Moore briefly mentioned several other studies, one of which, in Utah, found levels of ozone above EPA standards.

Gas transmission and storage has been claimed to be a major source of leaks of methane and ozone precursors near pipelines. Moore cited as relevant in this regard one study that used mobile mapping along roads in Boston and found hundreds of methane leaks, some producing concentrations more than 15 times global background levels and occasionally at levels that pose an explosion risk (Phillips et al., 2013).

In conclusion, Moore emphasized the critical lack of studies offering actual measurements. What is especially needed, he said, are targeted studies with measurements before, during, and after drilling; studies defining the emissions signatures from all shale gas formations so that the sources of emissions can be traced; more data on surface atmospheric fluxes of methane, especially in urban areas; and characterization of silica emissions. These steps, he said, must be taken to ensure public safety in the near and distant future.

Discussant Comments, Gabrielle Petron, University of Colorado-Boulder, and National Oceanic and Atmospheric Administration

Petron, an air quality researcher and associate scientist at the Earth Systems Research Laboratory of the National Oceanic and Atmospheric Administration and researcher at the Cooperative Institute for Research in Environmental Sciences at the University of Colorado-Boulder, reported that in the Rocky Mountain region, ozone formation has been a major issue in Wyoming and in Utah, which set a national record for ozone concentrations. This phenomenon appears to be associated with temperature inversions, especially in winter. The states have begun to reduce these exposures by taking emissions inventories and regulating the precursors. She noted that reducing volatile organic compound emissions has a cobenefit by reducing emissions of greenhouse gases. She said that state ozone monitoring in Colorado does not yet occur in regions near gas fields. There is an effort ongoing to redeploy the monitors toward urban areas and areas of oil and gas activity.

Petron said that her group monitors emissions from towers, aircraft, and in situ, and has been monitoring from vans since 2007. It sees impacts of oil and gas activities daily, tries to pinpoint leaks, and has found measurement from airplanes very useful for identifying which parts of a region have higher methane levels. The measurements indicate that

benzene and methane correlate very highly in this region. However, there is a need to monitor other types of emissions as well, including emissions of additives such as acids, biocides, and solvents.

Petron discussed the importance of getting good measurements of methane emissions. She presented data indicating that the variation in EPA's estimates has been even greater than the 33 percent change that Moore mentioned. She then reported on an as-yet unpublished study by her research group, based on measurements of methane losses at three locations. It estimated a loss of 4 percent of extracted methane in the Denver basin and a 9 percent loss in the Uintah Basin. This estimate is much larger than EPA's estimates of a 1 percent loss from production and processing activities and a 1.9 percent loss from the full gas cycle. It is also higher than the 3.2 percent estimate given for gas in a study claiming a net climate benefit of gas compared with coal as the fuel for new power plants (Alvarez et al., 2012).

She concluded by identifying three priorities: (1) quantify actual emissions, especially fugitive emissions, with more field measurements: Petron said scientists have been using emissions factors from the early 1990s; (2) estimate emissions reductions from best management practices, which Petron said is being done in an ongoing University of Texas study; and (3) develop an effective and scalable leak detection program, with instruments that are usable by the industry for self-checking. Because there have been some strong, quantifiable impacts in some regions, new monitoring and detection techniques need to be deployed to assess and address the problem. The knowledge exists for capturing emissions for green completions, as has been done in Colorado, but that knowledge is not always used, Moore said, as indicated by high observed emissions at some sites in Utah and in Dish, Texas, where observed concentrations varied from less than 5 ppm to 30 ppm.

Questions and Discussion

Participant questions and comments opened several topics of discussion, which the rapporteur has summarized below under headings of Petron's measurements, relative emissions, monitoring, screening approaches, and variations in regulations.

Petron's measurements. In response to a question about the durations of emissions measured by Petron's equipment, she said that the measurements are over very short times—usually less than an hour—for the purpose of detecting problematic sites; they do not provide quantitative estimates over time. She said that to identify a chronic source of emissions would require measuring over several days. In response to another ques-

tion, Petron said that her measurements of methane releases in Colorado and Utah are for the whole of the natural gas system at the measured sites and acknowledged that not all the emissions are due to natural gas production (some may be from oil). She said that further measurements will help distinguish emissions from old and new wells. In response to a question about measuring aerosols, Petron said that this is being done by the National Oceanic and Atmospheric Administration, but her presentation focused on the emissions that are now of greatest concern to state governments.

Relative emissions. A participant asked how air emissions from shale gas development compare to other emissions; for example, how emissions from a gas well compare with emissions from a gas station on a freeway. Petron replied that in oil and gas development areas, emitted benzene is coming mostly from these activities and not from transportation, although this varies case by case. In the Barnett shale, there is very little benzene, but it may be much greater in other shale plays. Moore suggested that as more is learned about point sources of air emissions from gas wells, stakeholders may want to require controls as is done now in California for gas stations.

Monitoring. A participant asked about the status of methane monitoring technologies. Petron said the technologies are ready to use and their adopters are starting to produce publications. She said that measurements from airplanes can provide isotopic signatures that allow emissions to be attributed to particular sites. Monitoring in Colorado costs about $200,000 per month for a gas field, Petron added, while in Texas it costs about $350,000 per month because of the need to send a crew to the site.

Robert Jackson, of the Duke University research team, supported the need for monitoring in many places, not to document high concentrations or get averages but rather to examine the relationships among many gases from above (from a plane or a skyscraper) to identify the sources of the emissions. He also suggested that a lot of progress can be made by collaboration with industry. Moore agreed that long-term monitoring projects are desirable if there is agreement on what needs to be monitored. Petron agreed about the need to be able to differentiate between gas emissions from feedlots and natural gas production but said that current practical capability is far from that goal. She also noted that monitoring by the National Oceanic and Atmospheric Administration at eight towers and from aircraft has been cut back because of tight funding. Jackson said that air emissions represent the area where the greatest progress can be made most quickly and that it presents a multiwin situation because of safety, economic benefits, and air quality. He expected that in a year

much more will be known about air emissions than is known now. David McCabe of the Clean Air Task Force expressed the opinion that although measurement in collaboration with industry is very important, it is hard to assess the gross emitter problem in close collaboration with industry, so independent government and university measurements are also valuable.

Screening approaches. McCabe suggested that as with vehicle emissions where it is often one vehicle out of ten in a fleet that produces most of the emissions, a key approach for gas well emissions is to find a way to screen to find the few major sources. He suggested that one does not need isotopic signatures to "prove" that the source has been found. He mentioned an EPA study of gas processing plants a decade ago that found that leak rates varied by a factor of 50 across plants; in each plant, emissions were dominated by the top 10 leaks out of thousands, and the top 10 leaks from the single leakiest plant accounted for 35 percent of all the leakage in the entire study. Petron agreed about the value of easy-to-use screening devices, especially because the industry could use them to find and close their leaks and because there are only a few government regulators available—only 17 inspectors in all of Colorado, for example. She believes that within the next few years, it will become fairly easy to find the leaks.

McCabe said that the regulators need something specific to localize the source of a leak, and Petron replied that available one-second measurements make it easy to see where emissions are coming from. She disagreed with some of McCabe's comments, however, noting that methane is not the only emission needing measurement and specifically mentioning volatile organic hydrocarbons. She also said that isotopic measurements are needed for observations from planes because that is the only way to trace the sources of the emissions.

Variations in regulation. There was a brief discussion about variations in regulations across jurisdictions, and even within a single state. Petron said that within Utah, regulatory authority differs between Indian land and other locations.

PUBLIC HEALTH RISKS IN SHALE GAS DEVELOPMENT

Presentation by John Adgate, Colorado School of Public Health

Adgate, who chairs the Department of Environmental and Occupational Health at the Colorado School of Public Health and whose research focuses on improving exposure assessment in epidemiological studies, organized many of his comments around a health impact assessment his group conducted in Battlement Mesa, Garfield County, Colorado. He

noted that public health risks result from contact with stressors, including both direct and indirect effects through environmental and social processes. Stresses may arise during the short-term well development process, the production phase, and afterward. Different kinds of stressors can arise at different phases, leading to public health risks.

Air exposures. The Adgate group's health assessment focused a lot of attention on air quality issues. It gathered existing information from county officials and state records, such as local air monitoring data, traffic, and noise estimates; anecdotal reports of exposures and health symptoms; demographic and vital statistics data; data on cancer and other diseases; and school and crime data. It also examined the scientific literature to help think about possible exposures. It is important to note that complete exposure information and health outcomes data were not available. The group looked for potential impacts on acute diseases and cancer; accidents, fires, and explosions; and community changes that might affect activity levels, social engagement, and psychosocial stress among individuals.

Adgate said that the assessment led to some straightforward recommendations, which nevertheless proved controversial—for example, to reduce exposures, promote safe operations in residential areas and foster constructive interaction among stakeholders. Adgate noted that there is increasing concern about shale gas development in Colorado because it is now moving into populated areas.

The health risk assessment (McKenzie et al., 2012) emphasized the need to manage flowback, which seemed to be the most significant source of emissions. A 2011 EPA study found that methane, hazardous air pollutants, and volatile organic compounds were emitted at about 20 times the level in fracked gas wells as in unfracked wells. Using a limited number of "flowback" and nonflowback water samples, the group applied a standard screening risk assessment method that produced a hazard index for noncancer health risks and estimates of lifetime excess cancer risk. The hazard index fell below the line indicating that health effects might occur for most populations, but not for subchronic risks for people living near the wells. Using a 20-month exposure scenario, the hazard indexes were above the cut-off line of 1.0 for neurological, respiratory, and hematological effects, but not for developmental effects. The most important noncancer risk driver was trimethyl benzenes.

Lifetime excess cancer risks were assessed to be above a 1-in-a million target level but well below the 1-in-10,000 level that calls for EPA remediation. Benzene was the primary driver of lifetime excess cancer risk. Adgate emphasized the preliminary nature of these results, saying there are lots of limitations to the data.

Water exposures. Adgate said that the same risk assessment approach can be used with water exposures, but assessments using this approach have not yet appeared in the literature, despite the high level of public concern about water. A large number of chemicals go into fracking fluids, but much less is known about what comes out in the form of flowback from the high-temperature, high-pressure environment below the surface. Disposal practices are likely the most important source of risk because of the contents of the flowback fluids.

Industrial activities. Industrial activities and sand mining expose workers to silica and bring the risk of silicosis, Adgate said. In his group's health impact assessment, truck traffic was a big complaint. Truck trips have been estimated at 1,000 per well in New York, with multiple wells per well pad. Thus, Adgate concluded, living near that level of traffic poses hazards such as exposure to diesel fumes and dust and risks to the safety of school children. Industrial safety culture can also be an issue. A report in Wyoming found worker fatalities occurring at two to three times the national rate, mostly on drill rigs and in transportation.

Other stressors. Adgate's group found noise levels within 1,000 feet of wells in Colorado to be high enough to be a stressor. He noted an emerging literature on relationships between noise and cardiovascular disease. The health impact assessment also noted that increases in arrests and sexually transmitted diseases were positively correlated with the large increase in well starts from 2005 to 2009. Local residents also reported increased stress, insomnia, and other reactions. Adgate mentioned a recent report by Kyle Ferrar at the University of Pittsburgh that found that among 33 people who believed their health had been adversely affected by shale development in the Marcellus basin, the top stressors mentioned were all social (Ferrar et al., 2013). They included being denied information or being misinformed, corruption, and complaints or concerns being ignored.

Adgate emphasized the almost complete lack of information on exposures to health stressors and a lack of health tracking information, including information on occupational health. He argued in favor of greater transparency and better information aimed at the following objectives: (1) to characterize the range of activities and environmental factors relevant to smart setback policies; (2) to describe the variability in emissions, air levels, and human exposures; (3) to estimate toxicity factors; (4) to understand the effects of chemical mixtures and of noise, traffic, and accidents as stressors affecting health and quality of life; and (5) to incorporate better measures of stress into individual and community-level health assessments. He said that systematic data collection before, dur-

ing, and after shale gas development continues to be needed for data on exposure and health and that more study is needed on chemical mixtures as stressors and on nonchemical stressors, as these stressors affect both workers and communities. In addition, public health exposure-prevention strategies should also be directed at minimizing exposures during completion activities.

Discussant Comments, David Brown, Southwest Pennsylvania Environmental Health Project

Brown is a public health toxicologist who has served as chief of environmental epidemiology and occupational health in Connecticut. He currently serves as an environmental health consultant to the Southwest Pennsylvania Environmental Health Project, a nonprofit group organized to assist residents of Washington County, Pennsylvania, who believe their health has been or could be affected by natural gas drilling activities. He reported on work done by that project to identify patterns of health effects in exposed residents in southwestern Pennsylvania, to track the exposures, and to advise residents on ways to protect their health. The project is supported by three foundations and has the goal of providing "accurate, timely, and trusted public health information and health services associated with natural gas extraction." He emphasized the issue of trust because mistrust of health information in the region is so great that people are unwilling to even talk with strangers about these issues. In his project, an experienced nurse practitioner visits people who contact the project and provides examinations to arrive at health evaluations. The project offers the only physician education program available in the Marcellus shale region and provides clinical toxicology profiles to the nurse practitioner so that she will know the potential effects of exposure to relevant chemical agents when she talks to people who may have been exposed. The team also includes public health and occupational health professionals, a toxicologist, and a community outreach specialist.

The primary goal of the project is to identify and address health impacts by identifying the probable or possible causes of these impacts and determining actions that can be taken to reduce the stress level in this population. The nurse practitioner uses a structured interview schedule that asks about symptoms, when they appeared, the person's proximity to environmental sources, and social or emotional factors that may be associated with the symptoms. She usually spends 45 minutes talking with people before asking any health questions.

The client population has reported skin rashes or irritation (48% of individuals), nausea or vomiting (45%), abdominal pain (38%), breathing difficulties or coughing (41%), and nosebleeds (21%). Other common

complaints have included anxiety and stress, nervous system problems including headaches and dizziness, and eye and throat irritation. The nurse practitioner's reports include her assessment, based on the interview and her experience, of what she thinks is the client's situation with respect to exposure-relevant symptoms.

The project creates a case file on each person. It considers symptoms to be attributable to shale gas drilling based on three criteria: the temporal relationship between gas extraction activities and the onset of symptoms, the presence of an identifiable exposure source proximate to the individual experiencing symptoms, and the absence of an underlying medical condition that was at least as likely to have caused the symptom. The case records are reviewed by a team including a toxicologist, an occupational physician, a nurse practitioner, a psychiatric nurse practitioner, and two public health researchers, with the objective of determining for each case whether shale gas exposure can be ruled out. The reviews consider only the individual interviewed in each household. The population is self-selected—it consists only of people who approached the project, and all clients are in Washington County.

The analysis of the cases found dermal effects in seven people, all attributed to water exposure, and respiratory (13), neurological (3), and eye irritation (4) effects, all associated with air exposures. The group initially assumed that exposures would be through water, so was surprised to identify people with no water exposure who had symptoms attributable to shale gas operations. The results were consistent with some other research studies (e.g., Ferrar et al., 2013; Steinzor et al., 2013). The group noted that clients also reported health problems in pets, which created additional stresses for the clients.

The project's nurse practitioner also surveyed 279 people who presented with complaints to a clinic in Burgettstown, Pennsylvania, during 2 months in 2012-2013. She found that this group scored below norms on each subscale of a standard psychiatric test and that at least 30 percent of respondents were at risk of depression, compared with a national average of 19 percent. These findings go beyond anecdotal data, but are still clinical. Brown sees the findings as indicating a significant public health problem.

The project tried to reconcile its clinical data with literature indicating that there have been no exposures in the study area. To do this, it undertook some environmental measurements, such as monitoring airborne fine particulates for 4-5 days in homes located about 1,000 feet from compressor stations. It found long periods with fairly stable background particulate counts of 1,000-2,000 per cubic foot of air, but there were shorter periods with peak counts of 7,000-8,000 per cubic foot. Measurements of volatile organic compound concentrations over weeks, months, and

the entire year showed similar wide fluctuations in readings and some periods of very high exposure. The data indicate that cloud cover, wind speeds, and other environmental conditions strongly affect air mixing and observed concentration levels. Brown concluded that serious modeling is needed to better understand the exposures.

The project's primary objective is to tell people how to reduce their exposures. Measuring fine particles can be a surrogate for all air exposures and can help people know when it is all right for their children to go out and play. The project hopes to be able to offer a simple screening test to allow people to connect measurements to action recommendations. It advises people to reduce outdoor activity and to remove children from polluted sources. It asks them to use filtration systems to reduce exposure to particles and gases, and it is evaluating different filtration systems in collaboration with a group from the University of Pittsburgh. Inventorying emissions near clients' homes can reassure people who are not exposed: some people are panicked even 7 miles away from sites. Finally, the project asks clients to maintain environmental and health diaries.

The project offers clients "three good things to do": clear the air by managing home ventilation, cleaning the house often, and avoiding tracking in dust; use clean water for cooking, showering, and drinking, and see a doctor if water use appears to burn skin or cause rashes; and look for health changes by keeping a health diary, checking water, monitoring air, and paying special attention to children, the elderly, and the chronically ill. The project also suggests reducing noise and light pollution in homes. If clients cannot follow these guidelines, the project advises them to consider relocating temporarily or permanently.

Brown concluded by saying that to understand the health effects, it is necessary to do basic public health work: conduct needs assessments, get health information and information about the chemicals, identify the plausible routes of exposure, and make recommendations for reducing it.

Discussant Comments, Tiffany Bredfeldt, Texas Commission on Environmental Quality

Bredfeldt is a senior toxicologist at the Texas Commission on Environmental Quality (TCEQ), where she focuses on human health risk assessment in relation to ambient air quality. She began by noting the concerns raised by several workshop participants about lack of data and suggesting that because of differences in geological and meteorological conditions, the public health issues are likely to be region-specific. She also noted that regulations need to be data-driven and tailored to community needs.

She described the Barnett shale region, where she works, as highly urbanized, with many air monitoring stations. For evaluating the impacts

of shale development, Bredfeldt said that Texas is adding mobile monitoring stations at a cost of about $250,000 each, as well as canister samplers that cost $75,000 to $125,000. She noted the rapid development in the Barnett shale: when the TCEQ first started thinking about impacts on air quality, there were fewer than 1,000 Barnett gas wells; there are now over 15,000. Bredfeldt showed a TCEQ graph showing that although ozone levels are above health guidelines, they have not increased in the region over the past 20 years despite the large increase in the number of gas wells. Benzene concentrations are well below levels of concern and also have not increased with the increase in shale gas wells.

She did identify some site-specific issues. For example, benzene concentrations in Longview increased over the decade before 2007 until in that year they exceeded the 1.4 ppb level that the TCEQ had set as the level of concern. Mobile monitoring identified the source of the emissions as a single well. By attending to this well, benzene concentrations in 2008 were brought back below the level of concern. The 7,000 TCEQ helicopter flyovers, which can identify volatile organic compound plumes by infrared photography, have found 88 cases of emissions causing concern.

Short-term monitoring efforts indicated that carbonyls, nitrogen oxides, and sulfur compounds did not exceed levels of concern for short-term exposure and that less than 5 percent of volatile-organic-compound canister samples exceeded levels of short-term concern in terms of health or odors. Bredfeldt said that the TCEQ responds to complaints, most frequently about odors but sometimes about runny noses or scratchy throats, and that a complaint from an area near facilities with a history of noncompliance brings TCEQ staff to the site within 12 hours to take measurements and get the specifics of the complaints. This approach has been very helpful in finding the sources of problems.

Bredfeldt said that the TCEQ collaborated with the U.S. Department of Health and Human Services on a study of the town of Dish in which blood and urine samples were collected from 28 individuals to look for biomarkers of exposure to volatile organic compounds. The TCEQ did not find concentrations high enough to conclude that there were problems specifically from volatile organic compounds.[9]

She said that the TCEQ experience indicates that nearly all the documented issues arose from human or mechanical failures that were quickly remedied and could have been avoided through increased diligence on the part of the operator. The needed corrective actions normally amounted to little more than replacing worn gaskets, closing open hatches, and repair-

[9]The study report is available at http://www.dshs.state.tx.us/epitox/assess.shtm [June 2014].

ing stuck valves. The commission has engaged in outreach and education for operators and developed new rules in the form of best management practices for well sites to avoid exposures. This information, along with much else, is available on the TCEQ Website.[10] TCEQ public education efforts have also included open houses. Bredfeldt invited workshop participants to explore the TCEQ Website for further information.

Questions and Discussion

Participant questions and comments covered several topics of discussion, which are summarized below under headings of measurement and methodology issues; quality of epidemiologic knowledge; the case of Dish, Texas; and behavioral changes.

Measurement and methodology issues. In response to a question about whether variations in chemical concentrations in the homes studied by Brown's project could have been due to cooking and other household activities, Brown replied that measurements are made every hour for 24 hours and daily for multiple days, the monitoring takes account of in-home activities, and examining variability over time both within and outside the home can determine whether the source is inside or outside.

A participant asked if the high risk of depression reported in Washington County could be attributed to high rates of unemployment, poverty, or other causes. Brown replied that Washington County is not a low-income area and added that his project has extensive information on social and economic stressors for each individual and will be teasing these issues out. Another participant noted that the Washington County data were from people attending a clinic, who may be more prone to depression than average residents. Brown indicated that the sample also included people who drove patients to the clinic and added that his project intends to consider this comparison and other possible sources of insight.

At another point in the discussion, Brown commented on the dangers of using national reference values for populations that are under stress and are experiencing a combination of chemicals and fine particles. He said that it is known that fine particles act synergistically with chemicals and suggested that therefore, when fine particles are present, general reference values are not very useful. He was concerned that by relying on reference values, experts might be in the position of telling people who present with valid symptoms that they are not sick.

[10]TCEQ Website is http://www.tceq.texas.gov/airquality/barnettshale [June 2014].

Quality of epidemiologic knowledge. In response to questioning about whether there are any strong epidemiologic studies being conducted about the public health effects of shale gas development, either generally or on children in particular, the panelists said that they did not know of any. Alan Krupnick of RFF indicated that the Geisinger Health System, which operates in Pennsylvania, is working with RFF on a screening study examining their clients' health data. He believes the Geisinger Health System is doing a major epidemiologic study in collaboration with a researcher at Johns Hopkins University. Another participant emphasized the need to start any public health study before the population is exposed, follow the population over time, and also follow workers' health.

Bernard Goldstein raised questions about the willingness of responsible authorities to support good epidemiological studies. He said that of the 52 members of the shale gas commissions set up by President Obama and the states of Maryland and Pennsylvania, none had any health background; although there were good environmental organizations involved, no health organizations were represented. There were many state and federal government departments, but no health departments. He said that scientists are willing to do the studies, such studies are feasible (e.g., the Geisinger System and other groups could compare health conditions in areas with and without shale gas development), and Colorado had made a good start on a health impact assessment but was not able to complete it. Goldstein expressed doubt that the potential funders of such studies are willing to have them done.

The case of Dish, Texas. Some participants asked about the TCEQ's failure to find evidence of serious exposures in Dish, Texas, where there have been multiple complaints. Bredfeldt replied that the TCEQ does not have monitors everywhere in Dish and speculated that much of the concern there was attributable to nuisance factors such as noises and odors. Gabrielle Petron responded that her research group has data on Dish and commented that some of the well pads there are very close to the town hall and to playgrounds. Dish has the dirtiest well pads she has seen in 5 years in the field, she said, and she offered to work with the TCEQ and share measurements. She said her group's night measurements showed high levels of the subset of toxic chemicals they monitored. She expressed concern about the need for more exposure assessment. Bredfeldt expressed interest in sharing and comparing the two groups' data and reiterated her point that the TCEQ data are incomplete.

An Internet participant asked if there is an explanation for the lack of any increase in air pollutants in Texas shale gas areas despite the very great expansion of shale gas development there. Bredfeldt responded that Texas has been extracting oil and gas for a long time, so it has the best

record for developing and implementing these technologies safely. She noted that the biggest problems are user error and that these do not occur when operators take care. She said that the state's monitoring is extensive enough to detect emissions.

Behavioral changes. In response to a question about Brown's clients' receptivity to the information they were given on how to improve their health prospects, Brown said that although they do not monitor to see if the clients had made recommended changes, he believes that once they are confident that the project is focused on their health, they do pay attention. He reported anecdotally that they do buy meters, try to filter the air in their homes if they can, take their shoes off when they enter the house, and so forth. But he added that to get these changes, you must speak with them in person. He added that his project plans long-term follow-up on the question of behavioral change.

ECOLOGICAL RISKS OF SHALE GAS DEVELOPMENT

Presentation by Zachary H. Bowen and Aida Farag, U.S. Geological Survey

Bowen is Ecosystem Dynamics branch chief at the Fort Collins Science Center of the U.S. Geological Survey. He began by acknowledging a large group of collaborators in federal agencies and elsewhere who contributed to the content of his presentation, which is based on examinations of unconventional oil and gas development generally, not only hydraulic fracturing for gas. He emphasized the variety of ecosystems in which deposits exist and noted that over the past century, oil and gas development has occurred in many areas where new deposits are being developed or may be.

Terrestrial ecosystems. The direct effects of shale gas development on terrestrial ecosystems include removal of habitat, fatalities of animals by collisions with equipment, and the introduction of invasive species, typically plants, brought in by disturbance of soil and by human activity that may introduce seeds. Indirect effects may result from dust generated by trucks and construction activities, noise, light, avoidance by wildlife species of the development area, and at a larger scale, habitat fragmentation that can alter habitat use. The end points of concern are physiological changes that affect survival or reproductive success. Cumulative effects can result from the increasing scale of activity.

Bowen said that surface disturbance is easily quantified and that several research methods are available to measure it and estimate its effects.

These include spatial analysis (mapping and estimating development patterns); species-based modeling of population changes, behavioral responses, and habitat modeling; vulnerability assessment of habitats and of species distributions; and ecoregional assessment that considers multiple species and multiple drivers of change in larger geographic areas. Analysts increasingly realize the importance of incremental development, which can have effects going beyond those at particular well sites. Bowen illustrated some difficulties of measuring surface disturbance due to such factors as different types and degrees of disturbance at different spots at a well site or a single well pad being connected to multiple wells, which often creates greater surface disturbance than does the pad itself. He noted that renewable energy development, such as for wind energy, also creates significant surface disturbance and that there has been little measurement of this.

Bowen illustrated the state of research on terrestrial ecological impacts with a few recent studies. A study of the effects of gas development in Wyoming on mule deer habitat (Sawyer et al., 2006) showed that the deer avoided areas around wells and roads and moved into areas they formerly did not use. Further studies of the effects on migration routes, winter range, and reproductive success are being used to consider strategies to mitigate effects. Other research in the West has considered the habitat of sage grouse, a species being considered for federal listing as endangered or threatened (e.g., Knick et al., 2013). This research has quantified the extent to which the grouse avoid areas of human development, including areas with power lines, pipes, etc. Other research overlays changes in the landscape with model-based predictions of habitat suitability for species of interest, to develop maps of vulnerability. Ecoregional assessments consider effects at larger scale and involve mapping the concentrations of species of interest against maps of development. He emphasized that the location of disturbance matters a lot to the ecological effects.

Bowen briefly described a water quality study at watershed scale in which he is involved. It found that of 837 watersheds examined that were potentially affected by shale development, only 153 had adequate water quality data to look for trends. This finding indicates that the existing network of water quality monitoring stations is not extensive enough to evaluate effects of shale gas development on water quality in enough places to draw general conclusions.

Bowen summarized by making these points: (1) the distribution of shale gas resources and the methods used to develop the resource determine potential surface disturbance; (2) habitat requirements and behavioral responses to development are species-specific; (3) species responses must be known or estimated to predict effects of development, but population responses are difficult to predict precisely; (4) vulnerability of

species, communities, or ecosystems to potential development is typically assessed by examining areas of overlap and optimally considers the sensitivity of the affected species; and (5) ecoregional assessments examine multiple natural resources and are potentially useful in identifying priority areas for development or conservation. Bowen closed with the statement that we know a lot more than we used to about species responses.

Aquatic ecosystems. Aida Farag, a fish biologist who is station leader at the Jackson Field Research Station of the U.S. Geological Survey, spoke about aquatic ecosystems, pointing out that several stages of the hydraulic fracturing water cycle can affect them. She noted a history of looking at effects on aquatic organisms: the National Pollutant Discharge Elimination System under the federal Clean Water Act includes a permitting process for potential discharges into surface water under which the discharger can be required to test the effluent on aquatic organisms to determine whether the water is acceptable for discharge. Shale gas development can directly affect water quantity, quality, and infiltration through the levels of salts and trace organic compounds in produced waters. Indirect effects may include effects of produced water on the solvent absorption ratio and the ability of waters downstream to absorb water, the effects of dissolved solids and trace metals, alterations of flow rates and seasonal cycles, reduced diversity of habitat patches, and increases in non-native species.

Farag illustrated aquatic effects with photographic illustrations and reported findings from some studies. She noted that produced water is useful in some cases for agriculture but can also be toxic to aquatic organisms. Work to assess the effects begins in the laboratory and then moves to the field; it progresses from studies of individuals to studies of populations. At the intersection of laboratory and field studies and of individual and population effects are the mechanisms of toxicity, such as effects on ionoregulation, enzyme effects, and effects on estrogen and androgen receptors. Toxicity thresholds are set based on laboratory studies first and then on effects found in field settings. A study of a fish kill in Kentucky (Papoulias and Velasco, 2013) illustrates the histological and physiological effects of exposure. Such studies are preludes to basin-wide studies using in situ bioassays and reporting survival rates of species in untreated discharge water. Farag said there have been recent studies of brine contamination in wetlands near development sites and of chemicals in drinking water. Although these studies have not examined ecological effects, such studies could be conducted.

Farag concluded her presentation with the following points: mitigation of surface disturbance can maintain diversity of aquatic habitat patches, an integrated scientific approach needs to balance beneficial use with potential toxicity, studies defining mechanisms of toxicity at the indi-

vidual level can provide explanations and possibly provide early warning at the population level, establishing toxicity thresholds and then conducting field studies can expand understanding, and long-term water quality monitoring data are essential for estimating effects on aquatic ecology.

Discussant Comments, Margaret Brittingham, Pennsylvania State University

Brittingham is professor of wildlife resources and an extension wildlife specialist at the College of Agricultural Sciences at the Pennsylvania State University, with research interests that include the effects of habitat fragmentation on bird populations. She discussed some ecological issues that are appearing in the eastern United States. In the East, and particularly in Pennsylvania, Brittingham said, there is complete overlap between areas of shale gas development and core forested areas, which have high ecological value. She especially noted the ecological importance of neotropical migrant songbird populations to the forest for insect control and other ecological reasons and the importance of amphibians. For example, 18 percent of the world population of scarlet tanagers breed in Pennsylvania. She expressed the goal of having shale development and restoration proceed in ways that maintain these populations because maintaining them is much easier than restoring them.

Brittingham noted that gas wells change the landscape very differently in the East than they do in the West and that the ecological effects of deep shale gas development are very different from those of shallow gas development. Shallow wells tend to take about one-fourth acre each, and forest cover restores fairly easily, she said, compared with the industrial style of deep gas development, which uses pads plus other local disturbances covering an average of 6.7 acres and sometimes as much as 50 acres, not counting the large impoundments that are sometimes present. The habitat fragmentation pattern is also very different with deep gas development—for example, roads are much wider. The extent of disturbance is indicated by the number of pads being built: over 2,350 in Pennsylvania between 2005 and 2011, half in farmland and half in forest land, with about a quarter going into core, formerly unfragmented, forest. She expects that roads will have a larger ecological effect than the pads themselves. For some species, they will act as corridors of dispersal, invasion, or hunting; for others, such as amphibians, they will act as barriers. A study in Alberta found, for example, that pipelines and roads increased wolf predation on caribou. The width of the corridors probably determines the ecological effects.

Brittingham cited a study in Bradford County, Pennsylvania, that found that loss of core forest (i.e., forest more than 100 m from a for-

est boundary) due to pipelines occurred at a rate twice that of the loss of overall forest. Roads have similar effects. A recent overview paper (Northrup and Wittemyer, 2013) offers a general summary of knowledge about effects of energy developments on wildlife and identified these major concerns: habitat fragmentation, the balance of species (with fragmented habitat favoring generalist over specialist species), the spread of invasive species, disturbance to sensitive habitats, and negative effects on biodiversity and ecosystem functions. Her group's research so far indicates a decline of forest interior species, an increase in human-associated species, and no change with early successional species. Invasive plants are showing up at 60 percent of surveyed pads, with their appearance dependent on road access. Some areas become drier and some wetter, affecting habitat for amphibians as well as stream erosion and flooding patterns. Increased noise and light, strongest during well construction but continuing near compressor stations, can affect songbird territories and the reproductive success of some wildlife species, with some benefiting and others losing out.

Brittingham mentioned some clear nonecological differences between the East and West that have implications for ecological effects. Much of the development in the East is occurring on private lands (93% of the pads in Pennsylvania are on private land). Private landowners generally lack the resources for planning that public landowners have, and governments cannot control the location of roads on private lands even if they know which locations would minimize ecological impact. Also, the surface land owner often does not own the mineral rights. These factors increase risk and uncertainty compared to the situation in the West. She also noted that many sites in Pennsylvania have only one to two wells. This pattern may be occurring because companies need to show some activity to keep their leases, and it may indicate that habitat disruption will continue for several decades before completion occurs. In Pennsylvania, only 16 percent of pads have been reclaimed and most reclamation is to grass, not to forest.

Brittingham concluded her presentation by identifying the following research needs: studies of thresholds for change for different species and groups of species, mechanisms underlying species responses (avoidance, mortality, reproductive disruption), and restoration methods (including intermediate restoration while development is occurring).

Questions and Discussion

Participant questions and comments opened several issues for discussion, which are reported below under the headings of collection of baseline data, possible factors affecting ecosystems, modeling ecological impacts for decision making, and the ecological importance of the Appalachian area.

Collection of baseline data. A participant asked what triggers the collection of baseline data on private lands, which are dominant in shale gas areas in the East. Susan Tierney noted that the Secretary of Energy Advisory Board on shale gas development, on which she served, suggested that a triggering process be used to collect baseline data, similar to what states use when development processes trigger environmental reviews. Brittingham added that state agencies fund monitoring, but there is no system for looking at the ecological changes occurring.

Possible factors affecting ecosystems. A participant asked if research has examined effects of belts that include roads, pads, and pipelines, to determine any cumulative effects on particular species. Brittingham said that researchers at Pennsylvania State University are developing indexes of fragmentation for 3 × 3-mile blocks and that the Nature Conservancy is also looking at fragmentation at various scales to develop measures of this type. Bowen added that the U.S. Geological Survey is trying to do ecoregional assessments that capture all sources of disturbance, but because of gaps in knowledge, a lot of seat-of-the-pants thinking is still needed to determine the sizes of buffers needed to protect particular species.

In response to a question about ecological effects of the conjunction of shale gas development and climate change, Brittingham said this is an important point to examine, particularly in Pennsylvania, because it is at the southern border of the range for many northern species and at the edge of stress from several harmful tree pests. In response to a question about whether the per-gas-unit surface impact of deep gas production differs from that of shallow production, Brittingham noted that the landscape change is structurally very different, in addition to differences in scale.

Modeling ecological impacts for decision making. A participant said that the Nature Conservancy is developing a model to help companies locate their sites in ways that would allow them to incorporate habitat considerations in addition to economic factors and regulatory constraints. This participant asked whether the science is well enough developed to allow models to deal with regional-scale ecological issues. Brittingham said that enough is known to allow scaling up, but that it is not clear how flexible industry is regarding where pipelines go, whether companies can share pipelines, and other larger-scale issues with ecological implications. She noted that the model is being built to allow modification as more is learned.

Robert Winthrop of the Bureau of Land Management said that his agency's ecoregional assessments examine large areas; as an illustration of size, one such assessment is for all of eastern Utah. The assessments,

which consider certain biological and physical conditions and change agents, can be used to identify areas needing protection in the development of oil and gas master leasing plans and in setting conditions for leases—for example, by requiring phased development—that consider various kinds of values. In the Utah case, these include scenic values.

The ecological importance of the Appalachian area. In response to a question about the ecological importance of the Appalachian area compared with other regions around the planet, Brittingham, while noting that she has an Appalachian mindset, said that this area does have global ecological importance. She noted the concerns with worldwide amphibian decline and said that the Appalachian basin is the heart of salamander distribution; similarly, neotropical migrant songbirds depend on this area and the boreal forest of Canada, which is also being disrupted.

IMPLICATIONS OF SHALE GAS DEVELOPMENT FOR CLIMATE CHANGE

Presentation by Richard Newell, Duke University

Newell is Gendell professor of energy and environmental economics and director of the Duke University Energy Initiative. He previously served as administrator of the Energy Information Administration (EIA) at the U.S. Department of Energy. Newell characterized his presentation as a first foray into understanding the impacts of shale gas development on climate change. It does not consider other risks of shale gas development or compare these risks with the risks of other energy technologies. He distinguished two main questions to be answered: accounting for the greenhouse gas emissions associated with shale gas development, and the implications of that accounting for decisions being made by producers, policy makers, equipment manufacturers, and individual consumers. Accounting efforts include those that seek to estimate total life-cycle emissions and those focused at the sectoral level (e.g., comparing emissions from gas versus other technologies for particular purposes, such as for power generation). To inform decisions, Newell said, we need to consider the future both with and without changes in policy.

Greenhouse gas accounting. Newell explained that the available evidence includes baseline national emissions statistics, EIA data, studies from academia and NGOs, technology life-cycle analysis, and energy modeling projections such as those in the EIA's *Annual Energy Outlook* and projections from the International Energy Agency. The EIA models incorporate several scenarios, including a reference case and other cases that vary the

outlook for gas and oil. The high oil and gas resource case (which includes development of tight oil)[11] doubles shale gas development over the reference case. Similarly, the International Energy Agency offers a world outlook that includes a case with greatly increased gas development globally.

In the United States, Newell continued, total natural gas use divides roughly in thirds among power generation, industry, and commercial/residential uses, and substitution can occur in any sector, not only in power generation. In 2011, natural gas accounted for about 26 percent of U.S. carbon dioxide and methane emissions. Globally, shale gas could technically increase reserves by 40 percent, although with current costs and prices, the economically recoverable resources are much smaller. Almost all the current development is in North America. Despite interest, exploration, and development in many other countries, Newell said, there is so far not much production. Shale gas has gone from virtually a zero share of U.S. gas production in 2005 to about 35 percent now, with one model projecting that it will reach about 50 percent by 2040. The effects of these developments have included a significant decrease in actual current prices of gas, as well as lower projected future prices of natural gas out to at least 2040.

The effects on climate are both direct and indirect. Lower prices, Newell said, cause fuel substitution of gas for coal, oil, renewable energy sources, and nuclear power—so substitution affects sources that are both higher and lower than shale gas in greenhouse gas emissions. Lower prices also lead to lower overall energy prices and therefore to increased overall energy consumption. Combining these impacts and their consequences for carbon dioxide and methane emissions (from both extraction and combustion processes) yields the net climate impact. Policy also impinges on these effects by affecting emissions, technologies, and production processes.

Newell noted that modeling these effects on a complex system requires some assumptions. He pointed out that in the U.S. economy, natural gas expenditures are 13 percent of energy expenditures and 1 percent of the total economy, which suggests that lower gas prices will increase gross domestic product (GDP), but probably not by much. He said that the substitution effect (using gas instead of other energy sources) will likely dominate the aggregate demand effect. Aggregate energy demand is mainly driven by population growth, overall economic growth, and the share of the economy represented by manufacturing versus services. The effects of prices are represented in economic models as demand elasticity: the aggregate demand effect is the percent increase in consumption associated with a percent decrease in price. EIA modeling indicates a very low

[11] "Tight oil" refers to underground petroleum sources such as oil shales and tar sands.

elasticity of aggregate energy demand with respect to natural gas price changes (elasticity less than 0.1, or a 1% increase in aggregate demand for a 10% decrease in price), a low-to-moderate elasticity of natural gas demand with respect to natural gas prices in the residential/commercial (elasticity less than 0.3) and industrial sectors (less than 0.5); and a much greater elasticity of demand for natural gas for electricity generation (1.5 to 2.5).

In the EIA models for the high-resource case, which assume a doubling of expected recovery of natural gas, gas prices are about 45 percent lower in 2040 compared to the reference case. Total energy use goes up by 3 percent, GDP increases by 1 percent, and cumulative emissions between 2010 and 2040 in carbon dioxide equivalents decrease by 0.4 percent. This modeling result, Newell said, indicates that fuel substitution dominates the other effects, leading to lower emissions, though not by much. Using other target years before 2040 presents a similar picture, he added.

According to the 2013 U.S. EPA greenhouse gas inventory, Newell said, 87 percent of greenhouse gas emissions from natural gas come from combustion. Noncombustion emissions have been variable, but have decreased in the past few years: Newell reported that according to the 2013 inventory, upstream emissions have decreased by 11 percent since 1990 per unit of production. He noted, however, that these estimates have fluctuated from 1 year's inventory to the next due to changes in methods of calculation. So different studies may get different results, depending on which year's EPA estimates they use.

Newell presented results from Weber and Clavin (2012), who compared several published estimates of noncombustion greenhouse gas emissions from conventional and unconventional gas development and found considerable variation across studies and no consistent difference across studies between shale gas and conventional gas. Newell indicated that if the latest EPA estimates had been used in all these studies, the average emissions levels would have been lower than they appeared in the studies as published.

Looking by sectors, Newell said, the studies mostly indicate that emissions from combustion are 40-50 percent lower with gas than with coal. The debate has mostly been about upstream emissions. The one outlier is a study by Howarth and colleagues (2011), which concluded that gas was worse than coal for greenhouse gas emissions. Newell thought that it may be an outlier for one or more of the following reasons: Howarth and colleagues used a 20-year global warming potential, rather than the conventional 100-year horizon; they assumed a relatively high methane leakage rate and assumed that it is all vented rather than flared; and they did not account for the greater efficiency of natural gas combustion compared to coal for power production.

Newell said that coal-based power production has decreased in the United States by 496 GWh between 2005, when serious production of shale gas started, and 2012. There have been accompanying increases in gas-fired power production of 470 GWh and in power production from renewable sources of 138 GWh, as well as a reduction in power from petroleum of 87 GWh. National greenhouse gas emissions are now said to be the lowest they have been since 1992, Newell said, adding that this is the combined effect of recession, lower gas prices, and increased regulation affecting coal power. The data, Newell added, indicate that fuel substitution of gas for coal has so far outweighed any effect of gas on power generated from renewables.

The EIA analyses, said Newell, suggest that in the power sector, a high oil and gas scenario reduces cumulative greenhouse gas emissions by 5 percent through 2040, for the same reasons as in the whole-economy model. As a rule of thumb, he added, if gas replaces more coal than nuclear, there is a net benefit for climate change, and this is what this model projects.

In the residential and commercial sectors, the evidence reviewed by Newell suggests that gas-fueled space and water heating has lower greenhouse gas intensity than electricity-generated heating, though this outcome depends on where in the country the gas is used. The modeling results are similar to what they are for the power sector: in the high oil and gas scenario, cumulative greenhouse gas emissions are 3 percent lower than in the reference case.

In the transport sector, studies comparing gas-powered and gasoline-powered light vehicles show decreased life-cycle emissions for gas of around 10 percent, according to Newell. In a similar comparison for heavy vehicles, which are conventionally diesel-fueled and more efficient, he explained, natural gas does not do as well as a substitute fuel. The industrial sector shows some of the same dynamics, he said, but the EIA model projects a slight increase of 0.3 percent in cumulative emissions.

International implications. Newell said that the international implications of all these model projections are important. The International Energy Agency's "Golden Age of Gas" scenario indicates that by the end of its projection period in 2035, greenhouse gas emissions will be 3 percent lower than under a reference scenario (International Energy Agency, 2012). These models involve a lot of behavioral assumptions about substitution that need to be examined, Newell noted. For example, there is a concern about U.S. coal exports, which will have a net climate effect only if they affect global coal prices; if they do not, they will only substitute for coal from other sources. U.S. coal exports account for only about 5 percent

of the international coal trade, Newell continued, so U.S. exports seem unlikely to have a major effect on global coal prices.

U.S. policy implications. Newell concluded by discussing some policy implications. Low natural gas prices may make certain climate policies easier and others more costly. For example, lowering the price of natural gas will make it easier to meet some climate policy targets because it substitutes for coal. It may, however, increase the relative cost of renewable energy standards, which will increase with low-price gas. To achieve substantial long-term goals for reducing greenhouse gas emissions, Newell said that increased use of natural gas would need to incorporate carbon capture and storage at reasonable cost to continue as a competitive option.

Newell summarized by saying that the greenhouse gas emissions intensity of natural gas has fallen and that further reductions in noncombustion emissions and improved combustion efficiency are feasible and could further this trend. Thus far, he said, shale gas has led to decreased greenhouse gas emissions by lowering prices and displacing more coal than renewable and nuclear energy sources; using current life-cycle estimates, natural gas tends to lower greenhouse gas emissions relative to coal-fueled electric power generation, gasoline-fueled personal vehicles, and electricity for space/water heating. But natural gas abundance alone will probably not, according to Newell, have a substantial effect on future greenhouse gas emissions. He sees policy as the key factor and added that natural gas abundance could influence relevant policy in ways that could have a substantial effect on future emissions.

Discussant Comments, Jason Bordoff, Center for Global Energy Policy, Columbia University

Bordoff is a professor of professional practice and director of the Center on Global Energy Policy in the School of International and Public Affairs at Columbia University. He formerly served on the White House National Economic Council and the Council on Environmental Quality. He emphasized that the key questions about climate effects are how much gas actually is available, what the substitution and demand effects of increased supplies will be in the United States and overseas, and how much better natural gas really is from a climate perspective.

Every piece of data suggests that shale gas is booming and will continue to do so, he said. The latest estimate of U.S. reserves is 26 percent greater than the previous one. New estimates continue to surprise on the up-side, Bordoff continued, though uncertainty remains about decline and recovery rates from unconventional wells. He said that substitution of gas for coal, changes in the economy, and wind-energy development

are among the main reasons for the decline of U.S. carbon emissions of about 12 percent since 2005.

The question of climate effects is, according to Bordoff, mainly dependent on the net of substitution and demand effects of increasingly available gas. Even if the net effect in the United States, as Newell's presentation indicates, is a reduction in emissions, Bordoff said that this will not "solve global warming." In the high-supply case, Newell's slides show only a 0.4 percent reduction in greenhouse gas emissions. The number is probably as small as it is, Bordoff surmised, because hydraulic fracturing produces oil as well as gas and the rise in oil production counteracts some of the net benefits of increased gas production.

Bordoff agreed with Newell that the study by Howarth and colleagues (2011) of fugitive methane releases is generally seen as an outlier. Most studies show that natural gas is roughly half as carbon-intensive as coal for power generation; with recent EPA rules on green completion, he said, this proportion will decrease, though much remains unknown about leakage in transmission and distribution. Still, Bordoff said, the sources of leakage, such as fugitive methane, can be reduced at a fairly low cost. Thus, in all, he concludes that shale gas production in the United States produces a net climate benefit.

At the international level, Bordoff said the questions are also about substitution and demand effects of increased gas availability, whether locally sourced or imported. There are enormous shale reserves in China, Argentina, and elsewhere, but he believes development will take time for reasons including difficult geology; requirements for water and for industrial and transport infrastructure; investment policy; and human capacity. There are reasons for pessimism about shale gas development in Europe, he said, partly because of difficult geology and partly because the gas there is mainly "dry," without the valuable hydrocarbon liquids. Even though development will take time, he expects the global supply of liquefied natural gas to increase. Gas prices in Europe and Asia, which have been much higher than in the United States, can be expected to drop because liquefied natural gas that might otherwise be exported from the Persian Gulf to the United States will become available for export to Europe. If more liquefied natural gas flows to the Pacific Rim, Bordoff continued, there could be downward pressure on gas prices there as well, leading to substitution from coal.

The International Energy Agency's *Golden Rules for a Golden Age of Gas* study (International Energy Agency, 2012) projects a three percent decline of global emissions, due to the combination of natural gas substitution for coal, oil, nuclear, and renewables, and increased demand. Bordoff said that it would probably take at least 5-10 years for new gas-fueled power plants to come online globally. He noted that electricity demand growth

is starting to slow in China, which implies a decreasing need for new power plants—unlike the United States, where there are many old power plants needing replacement, which makes gas-fueled power generation look more attractive. He believes that substitution for renewables and nuclear energy will mainly be policy driven rather than price driven. For example, if the European Union continues its renewable-energy mandate and its subsidies for nuclear power, substitution for these power sources would be less intense than in scenarios where greater substitution would increase the climate benefits.

In his summary, Bordoff said that although the effects of increased gas supplies on climate push in both directions, on net, they are still positive. The most important point, he concluded, is that whatever the economic effects, the main impact of natural gas will be to make it less expensive to enact policies to solve climate problems.

Questions and Discussion

Many issues arose in the discussion, and the rapporteur has organized these under headings of costs to consumers, responses in the industrial sector, methane releases, effects of particulates, liquefied natural gas exports, global economic development issues, and "what will be the ultimate effects on humanity?"

Costs to consumers. A participant noted that for consumers in some states, much of the retail price of gas is due to distribution and delivery costs and asked about the implications of this for the analysis. Newell agreed that the proportion of costs to consumers due to the price of gas vary greatly and are sometimes relatively small, so that decreased gas prices sometimes have a relatively small effect on prices to consumers. He said that these factors are built into the demand models.

Responses in the industrial sector. A participant said that there is very little in the literature on the market effects of the one-third of gas that goes to industry. Although those markets will respond in the short- and long-term, we don't know to what extent, the participant said. Newell agreed that there has been relatively little attention to substitution in industry, adding that some companies are relocating internationally and analysis needs to consider what emissions would have been if they had not moved.

Methane releases. A participant proposed that the uncertainties about methane releases are greater than the presenters suggested and expressed the opinion that the EPA data and the studies built on them do not repre-

sent the range of uncertainty. He said that a number of ambient-air studies show emissions in several basins of over five percent, indicating that the EPA-based numbers may be considerably too low. He also pointed out that studies are not looking at methane emissions from coal-fired power plants, which needs to be done for a fair comparison within the power sector. Newell agreed that there have been significant variations among studies. Bordoff added that there are methodological issues with the EPA analyses of methane, as well as with the ambient studies. He reiterated his view that whatever the emissions are, the problem is solvable at relatively low cost.

Another participant asked how much is known about fugitive methane emissions from old and abandoned wells and what might be done to get data on that. Neither presenter could answer the question, but Bordoff pointed out that the problem is not new: methane emissions have long been an issue with conventional gas wells.

Effects of particulates emitted from coal-based power production. In response to a participant's question, Newell said that his and other studies comparing gas and coal in power production have not looked at particulates, but his sense is that they are a small contributor.

Liquefied natural gas exports. A participant noted that these exports are very greenhouse gas-intensive and need analysis. Newell expressed the view that although liquefied natural gas is more energy-intensive than pipeline gas, the difference is not enough to outweigh the benefits of substituting gas for coal in electricity production. Bordoff added that liquefied natural gas exports to the Pacific Rim would likely have a net climate benefit, though there is considerable uncertainty about that.

Global economic development issues. A participant asked about the effects of gas supply and price in places where more people are seeking middle-class life-styles. Newell reiterated his view that the demand effect will not be the major one globally but that once people can afford such things as motor vehicles and domestic water heating and electricity, the main issue will be which fuel is used to meet these new demands.

What will be the ultimate effects on humanity? A participant said that because both gas and coal are fossil fuels, the debate about which has lower emissions is somewhat beside the point. She noted that even the *Golden Age of Gas* report indicates that a golden age for gas will not be a golden age for humanity. Bordoff responded that global economic growth and decreasing poverty are also policy objectives, and he pointed out that cheaper energy helps achieve these objectives. Susan Tierney, the modera-

tor of the discussion, commented that she had heard no one suggest that shale gas was a solution to climate change.

RISKS TO COMMUNITIES FROM SHALE GAS DEVELOPMENT

Presentation by Jeffrey Jacquet, South Dakota State University

Jacquet is assistant professor in the Department of Sociology and Rural Studies at South Dakota State University. His research focuses on social and economic impacts of energy development. His presentation aimed for a broad overview of what is known about the blessing and "curse" of natural resources to communities, discussing four types of risks and identifying four main gaps in knowledge. He pointed out that although community outcomes are usually long term, shale gas development is relatively new, so most of the relevant knowledge comes from other types of energy development in the past and from studies of environmental contamination and technological disasters.

Blessings and costs of natural resources. Jacquet indicated that the blessings are mostly related to jobs and economic stimulus. Natural resource development increases employment and tax revenues, especially in rural areas lacking other opportunities, but these blessings are relatively short term and come in booms and busts. The costs are longer term, he said, and include volatility, instability, and de-diversification of the economy; higher long-term unemployment, poverty, and inequality; and lower educational attainment compared to similar areas not experiencing natural resource development. World Bank country-level data show a negative correlation between fuels, ores, and metals as a percentage of national exports and economic growth rates, Jacquet said, and county-level data in the United States support the resource curse hypothesis, showing that total personal income in energy-focusing counties follows boom-bust cycles while other counties show steadier income growth. Data on nonlabor income shows a slowly increasing gap, he added, favoring nonenergy-focusing counties. A meta-analysis of 369 studies of economic impacts (Freudenburg and Wilson, 2002) showed that resource-dependent counties fared slightly better than other counties on measures of income but worse in terms of poverty, unemployment rates, and overall economic performance.

Boom town effects. The risks to communities of rapid industrialization, found by Jacquet in studies done over the past several decades, involve strained municipal services, poor quality of life, out-migration of residents, and a legacy of overbuilt and unplanned construction. Jacquet said that resource boom towns show rapid short-term population growth, with

the effects of this depending on the initial population that can absorb the impact, the pace of development, and the availability of funds to mitigate the impacts.

Inequality. Inequalities in the distribution of costs and benefits tend to increase with time, Jacquet said, and they often produce what Freudenburg and Jones (1991) called "corrosive communities." Landowners may get benefits that others cannot. In some places, split estate—the disconnection of surface land ownership from subsurface minerals ownership—is likely to contribute to the inequality effects, especially where mineral owners do not live in the community. The results, Jacquet continued, include fierce community conflict, distrust, litigation, uncertainty, and confusion about what is happening, blame-placing, and distaste toward those who benefit. The community conflict is often worse than the environmental impacts: community decision making suffers, communication breaks down, scientific facts become harder to obtain because of litigation, and out-migration and disinvestment often occur over the long term. Much social science literature, he added, indicates that unequal distribution of costs and benefits affects perceptions of risk and harm, attitudes about acceptability of the activity, perceptions of fairness, and trust within communities.

Jacquet's (2012) research among landowners in Pennsylvania found that 60 percent of those without gas development on their land thought development was making the community worse, people with leases but not yet with development were split in their opinions, and people with leases and development believed gas development was making the community much better off. General environmental attitudes also had a major influence on these judgments, he said.

"Contaminated communities." Research on communities that have been stigmatized as contaminated (regardless of actual contamination levels), such as the Love Canal community in New York and the area around Three Mile Island in Pennsylvania, indicates that this experience has powerful effects on residents' self-image and subjective sense of well-being (Edelstein, 1988). This kind of stigmatization is evident in numerous communities where shale gas development is occurring, Jacquet said.

Stress. Data on public health impacts often do not address social-psychological stress, said Jacquet, but there are effects on powerful place-based identities related to ideas of "what kind of place do I live in, what is my role in the community, and who are in my social circle?" A study in Gillette, Wyoming, in the 1970s (Weisz, 1979) found that on a self-reported stress scale, the average resident scored as having "major life stress" even though there was no environmental contamination. Half of the people

with that level of stress reported physical illness, compared with nine percent of people who were not stressed. Jacquet added that stress was found to be among the greatest impacts of gas drilling in Garfield County, Colorado. Around the Exxon Valdez oil spill, many people experienced symptoms of post-traumatic stress disorder.

In concluding his presentation, Jacquet said that the risks of rapid shale gas development are likely to be broad-based and to operate through social, psychological, and economic mechanisms. They are long term in nature, and perceived inequity is a major stressor. He emphasized that with these effects, perception is reality because it is perception that causes stress.

Jacquet identified four knowledge gaps: (1) What happens to the generated wealth? We know that wealth is generated, but know little about how or whether it stays in these communities. (2) What are the magnitude and effects of stress? We know that community change creates stress, he said, but we do not know its magnitude compared to other types of stress people are experiencing or its effects on health, conflict, and economic development. (3) What are the long-term effects of corrosive communities, inequality, and stigmatization on disinvestment or in- and out-migration, and how can these negative effects be overcome? (4) What is the long-term development picture? For example, should communities plan for multiple booms and busts? Jacquet concluded that targeted funding is needed to address these issues, conduct longitudinal analyses, revisit previous studies, and assist communities in planning.

Discussant Comments, Susan Christopherson, Cornell University

Christopherson is an economic geographer and a professor in the Department of City and Regional Planning at Cornell University whose research interests include economic development in older industrial regions, including the impact of natural gas drilling in the Marcellus shale. Her comments focused mainly on knowledge needs regarding community impacts. She emphasized that very few academics have studied community impacts in shale gas development areas, the topic is very controversial, and it is important not to neglect the intangible effects. She stressed the importance of an issue she heard in many of the presentations at the workshop: risks extend far beyond the well site. She cited risks related to trucking, sand mining, and other activities outside the shale gas plays and pointed out that 27 states have regions that will be affected by shale gas development. Also, although the costs will be concentrated in certain regions, benefits, especially in the form of lower gas costs, will be distributed across the entire population.

Christopherson agreed with Jacquet that available knowledge, which is mainly based on what has happened in rural communities, indicates

that the long-term effects on communities are generally poor. However, many of the shale gas sites in the 27 states are not in rural communities, and these places may be affected differently.

She noted that the available information has mainly come from case studies, which do not provide the strongest evidence. Some aspects of communities can be measured quantitatively (e.g., crime), but other important aspects have not been measured well, if at all. One is the stage of development of the shale gas resource, which cannot be measured by consistent methods across states. Another analytic problem involves understanding the financial impacts, which requires understanding who owns the land and mineral rights and where they live. A recent study by researchers at The Pennsylvania State University indicates that only 25 percent of the people obtaining lease and royalty payments live in the communities where the leases apply. Thus, Christopherson concluded, the economic data do not tell who is benefiting economically and who is assuming the risks.

Effects on pre-existing industries, particularly tourism and agriculture, and on the jobs in those industries, seem to be negative, she said, but have not been carefully measured. Long-term public costs (roads, professional emergency services, public safety and crime control, administrative and monitoring costs, health care) seem to be significant in some places, but again, there are no good data. Another unmeasured type of risk relates to local control issues. In New York, for example, many communities have taken action, usually passing development moratoria, out of distrust of the state and the industry. Christopherson concluded by saying that even though the wide variety of shale gas plays will have to be governed in many different ways, comparative information is needed to inform these choices.

Questions and Discussion

Topics and issues raised by participants' questions and comments are summarized below under six headings: effects of in-migration, community health effects, community-level effects, community relations with industry, "social capital" and resilience, and possible best practices.

Effects of in-migration. A participant asked about the effects of in-migrants on fishing and hunting pressure on wildlife. Jacquet noted that although actual data are hard to get, the demographics of the new workers suggest hypotheses: the workers are mostly young and male and come from areas that are more urban than the communities in which they are working. Christopherson cited other ways the incoming workforce can be very different from the pre-existing local population. In Pennsylvania, for

example, local hospitals have had to hire Spanish translators to deal with incoming workers of Mexican background. She noted that communities can respond better if they have a good idea of what they will face and what it will cost.

Community health effects. A participant said that it has been impossible to get worker health statistics for this industry because the work was so heavily subcontracted that it is hard to identify the workers. Another commented on the view that health effects in affected communities are mostly due to stress, saying that it is hard to tell whether this is true. He cited an example of a worker who presented serious neurological problems that could not be fully diagnosed because it was impossible to get access to the data on the chemicals to which the worker may have been exposed. Some of the most serious health effects are from accidents, he added, which are not stress-related. In addition, some stress-related responses, such as family break-ups, are not normally reported. Jacquet agreed that some of the health effects are due to contamination and some to stress, but he said that we do not yet know how large each portion is, or what the total is. Christopherson added that federal data collection is needed. She said that the Occupational Health and Safety Administration has not been engaged, which is one reason there is so little information about the risks workers face.

Community-level effects. A participant who had studied impacts in Pennsylvania said that communities are disintegrating: people have lost their social networks, and many people who have not yet left but who have developed plans to leave are the people the community most needs. He added that school attendance rates have fallen in the shale gas communities he studied.

Community relations with industry. A participant asked how community relations with the industry are affected when the companies in the industry are small and when the owners of the mineral rights are not in the community where the gas is extracted. Christopherson said that there are good relations between communities and some operating companies and wondered whether large oil companies behave better in Texas, where their employees live, than in the East.

"Social capital" and resilience. A participant asked whether research on social capital, community resilience, and responses to disasters has entered into the work on community risks from shale gas development. Jacquet said that although lessons need to be drawn from past research on these topics, generally speaking that has not been done. Research-

ers who try to draw lessons from experience, even with other kinds of energy development, receive criticism that it does not generalize. Jacquet said that the research on "corrosive communities" by Freudenburg (e.g., Freudenburg and Jones, 1991) has generally become a lost literature and needs to be reexamined.

Possible best practices. A participant suggested that the long history of extractive industries in the United States should offer instructive experiences, from places that claim to have done reasonably well, for formulating best practices to address negative impacts on communities, anticipate problems, and spread the benefits. An example might be the use of receipts from taxes on new industries to support education and other local public services. Christopherson agreed that there are possibilities of this kind, although there are important differences between states: in Wyoming, taxes go to the state government; in New York, to localities. Jacquet noted that after the Western energy booms of the 1970s, some state governments changed policies with the apparent result that the negative effects of more recent booms were lessened. He added that in the East, states do not have that experience as a basis for adjusting their policies.

In response to a question about whether there are success stories from local communities, Jacquet replied that rebound sometimes occurs: a longitudinal study in Utah indicated that quality of life decreased during the boom but rebounded by 20 years later. However, he could not identify a shining example of success. Christopherson said that anticipation of the costs and developing a plan are the best strategies for limiting community impacts, but she noted that development often happens in places that are not prepared and lack government capacity. Many rural communities in the Marcellus shale region have volunteer mayors with no paid staff. Where there is greater governance capacity, she said, communities are in better condition to cope with risks.

A participant asked about impact fees as a mitigation strategy and wondered how Pennsylvania (the only state with impact fees dedicated to helping communities) is faring with that approach. Christopherson replied that right now, there is no relationship between public costs and taxes or impact fees. In Pennsylvania, a community gets $10,000 for every conventional well and $50,000 for every unconventional well, she said, with communities that oppose development not getting any impact fees. She said there are no data on how these impact fees compare with the actual costs communities face; New York is collecting baseline data on some community conditions, such as road conditions, and there are some agreements being made with companies to keep up local roads.

Jacquet offered as a positive example the community of Evanston, Wyoming, where in the 1970s Chevron rapidly developed oil and gas

wells, quadrupling the size of the town. Chevron created the Overthrust Industrial Association to help the community, rebuilt the police station, bought school buses, and spent many millions of dollars on community facilities through partnering with local officials. He said that although there are many such examples of socioeconomic mitigation, the investments usually pale in comparison with the mitigation investments for wildlife and are usually limited to what is required by the landowner or the government. In the East, he said, people are impressed when a company donates a few thousand dollars to the 4-H Club, but there are greater needs.

Another participant said that he had once suggested to the state and federal governments in Australia, where the state owns all mineral rights, that they should take funds from the government's royalties from extraction to establish community trust funds. He asked what such funds should best be used for, if they were created. Jacquet said that trust funds can be a great solution and suggested that spending begin with community infrastructure (sewer and water systems, schools, health facilities, etc.), as has been done in Norway. This helps people see the community benefits of development, he noted. Christopherson suggested that the funds might also be used to level out boom-bust cycles, except where local officials are required to spend tax money in the year that it is received.

INTERACTIONS AMONG RISKS

Presentation by Alan Krupnick, Resources for the Future

Krupnick is director of the Center for Energy Economics and Policy at Resources for the Future (RFF), where he is engaged in a series of studies related to the sustainable development of shale gas. He reported on some research recently completed at RFF, organized around a risk matrix that identifies activities (e.g., horizontal drilling, flowback and produced water disposal), burdens (e.g., air pollutants, fracturing fluids), intermediate impacts (e.g., on ground water, air quality, habitat), and final impacts (e.g., on human health, ecosystems, climate, quality of life). The matrix identifies 264 "risk pathways" from activities to intermediate impacts. For example, site development includes on-road vehicle activity, which creates burdens of conventional air pollutants and carbon dioxide, noise pollution, and road congestion and intermediate impacts on air quality and community disruption. The survey did not ask about final impacts.

The RFF project surveyed experts who worked in four types of organizations: environmental NGOs, research universities, federal and state government agencies, and companies in the industry. The survey

sought the people most knowledgeable about these risks, and 215 experts responded (30% of those asked). The experts were asked to identify the highest-priority risk pathways in terms of the need for risk reduction through government or industry action. They were also provided with 14 accident categories and asked to identify those most in need of mitigation. By comparing the top 20 risk pathways identified by each group of respondents, Krupnick said the study found a lot of consensus about which risk pathways most need attention: 12 pathways were in the top 20 for all four groups, which suggested that it would be possible to reach agreement to work on those. There were also six pathways prioritized by the industry group and no other group; these were all community effects, indicating the industry's sensitivity to these effects. The project conducted several statistical analyses about the risk pathways, did a state-by-state regulatory comparison, and conducted a general public survey, the results of which Krupnick said were not yet available.

The "consensus" risk pathways included seven involving surface water, two involving ground water, two affecting air quality (both related to methane venting), and one involving habitat fragmentation. Seismicity was not a consensus concern. The people who identified themselves as "top experts" mostly agreed with the other experts but were also concerned about casing and cementing failures, either through leakage or accidents, leading to ground water contamination. These two pathways were among the top three concerns of all four groups of experts.

The comparison of experts' judgments of the highest risks, defined by their judgments of the product of probability and consequence, indicated some differences between groups. For example, the NGO experts considered some risk pathways to be high in both probability and consequence, said Krupnick, but very few industry experts identified any pathways of that type and were mainly concerned with risk pathways they judged to be of low probability and medium severity. The main differences among groups were in the judgments of probability. The risks that were judged differently in probability were casing and cementing failures and accidents, impoundment failures, and truck accidents.

The RFF group also conducted a study of surface water quality risks that examined statistical relationships based on the locations of shale gas wells and water monitors over the duration of shale gas development in Pennsylvania (Olmstead et al., 2013). It looked for chloride and total suspended solids downstream from wells and for the impacts of shale gas waste treatment and release of materials from waste treatment plants. It found no significant effects of shale gas wells on downstream chloride, showing no indication that spills had created a systematic problem for water salinity. Krupnick noted that the study did find elevated chloride concentrations in waters below waste treatment plants and identified rela-

tionships between the presence of wells and downstream concentrations of total suspended solids.

Krupnick described in some detail the conceptual framework his group uses for thinking about types of risks. He distinguished cumulative risks (which arise when multiple risk pathways affect the same actors) from synergistic risks (which arise when multiple associated pathways act together to make things worse). He also distinguished scale effects and interaction effects. He noted that risks that arise from flows (e.g., water withdrawals or air pollution) may not be cumulative if the stock recharges quickly enough, but can be cumulative if the pace of development increases beyond the capacity of the system to recharge. He suggested that habitat fragmentation from pipelines is an example of a cumulative stock burden because as the number of pipelines increases, habitat fragmentation increases. He noted that this relationship can be highly nonlinear, in that the results of fragmentation may appear only when a threshold level is crossed. Nonlinearity of effects also arises with regulations, which establish a threshold beyond which costs increase, and with water salinity because beyond a threshold level, salinity may make the water useless for crops. Methane emissions from shale gas production also produce a cumulative risk; the potential for explosion is probably a threshold phenomenon, Krupnick added.

Interactions among risks include chemical interactions involving similar burdens that produce hazards (for example, volatile organic hydrocarbons and nitrogen oxides interact to produce ozone), physiological interactions (e.g., exposures combined with pre-existing disease), interactions of burdens involving dissimilar pathways (e.g., surface water withdrawals and pollution of the same stream can cause greater damage than either burden alone), and interactions between shale gas burdens and other things in the environment. Krupnick noted that cumulative risk reductions can also be important. Some industry actions, such as recycling wastewater, reduce risk from multiple pathways simultaneously. Nonindustry actors (e.g., exposed individuals moving away from locations with exposure) can also reduce risk via multiple pathways.

Krupnick summarized by noting that there is much consensus about which risks most need attention; that a lot is known about the magnitude of many of the risks, but much less about others (such as those of habitat fragmentation); and that there is a great need to think about risks cumulatively rather than only in isolation.

Discussant Comments, Charles Perrow, Yale University

Perrow is an emeritus professor of sociology at Yale University whose research has focused on risks associated with structures and interactions

in large organizations and complex social and technological systems. He began his comments by saying that shale gas involves what some have called "destructive technology" in two senses. It brings innovation and introduces new products, so it is destructive to what it replaces. But it is also destructive in the usual senses of the word: its most important aspects are hidden from view, far below Earth's surface, and are impossible to anticipate or monitor. Contaminated water travels thousands of feet underground and interacts with nearby abandoned wells in surprising ways: in one case, sending a geyser of methane 80 feet into the air from a well that no one knew was there. Induced seismicity potential also exists and can sever lines from nearby wells and cause leakage, a possibility that Perrow said the recent NRC report on seismic risk did not consider (National Research Council, 2013). Although that report found only one case of induced seismicity from fracking, Perrow said that other sources in the literature indicate many more cases.

Perrow stated that some risks, including from toxic substances added to fracking water, are deliberately hidden by the industry. In many states, he said, it only takes a declaration that these are proprietary information to prevent disclosure. This makes it impossible, he said, for a homeowner or a community to prove that water that poisoned their wells and livestock came from a fracking operation.

Adequacy of regulations. Because this new enterprise has grown very rapidly, Perrow said, adequate regulations are not in place and regulating unexpected interactions producing risks will be very difficult. He said that most regulations are state and local and that regulators at those levels are poorly staffed, trained, and equipped to deal with the risks. Also, the 2005 Energy Act exempted the industry from provisions of the federal Clean Water Act, so that when the U.S. EPA can intervene, it has to do so under legislation that is limited in scope, such as toxic waste legislation. Thus, he concluded, shale gas development is a new destructive enterprise without compensating regulatory institutions. He said that the economic and political power of the oil and gas industry is effective in convincing states not to regulate and that states and counties are in the awkward position of protecting humans and the environment when they are also interested in the economic benefits that the industry can bring. He added that in some states, local governments are prevented from preventing or regulating shale gas development because of the state's economic interest.

Economic justice issues. Perrow stated that the benefits of this industry are unequally distributed to an extreme extent. He stated that the gas industry has received about $13.5 billion in subsidies in recent decades and that oil and gas combined are said to receive $10 billion in subsidies

each year. The gas industry is taxed at only 0.3 percent of its profits, which he said is probably close to a record low for any industry, even though this industry is one of the most profitable in the United States. Another economic justice question he raised involves property owners, some of whom receive large signer fees and royalties, while neighbors who do not receive the fees must use bottled water and live in fear of gas explosions. Property values decline (in some cases, by 75%), but full information about damages is lacking, he said, because gag rules associated with damage settlements hide information about the extent of damages. Perrow added that although local tax revenues can be substantial, they disappear in a few years after wells are exhausted. In Texas and Colorado, the state can deny petitions by landowners to prevent fracking activities on their land.

Methane releases. Perrow said that the industry releases methane at rates of two to seven percent and cited one scientific report estimating that it is more polluting than coal. He claimed that the public is not getting good independent estimates of methane emissions. Perrow agreed with what other speakers had said about methane leaks being correctable.

Corporate culture issues. He was pessimistic, however, about the possibility of changing corporate culture to reduce accidents. His research on organizational behavior indicates to him that the chances of changing corporate culture quickly for the better are very remote. He offered the example of BP, which had a massive leak from a facility in Prudhoe Bay, Alaska, after being warned by company engineers. Then, 2 years later in Texas City, Texas, BP had a deadly explosion after corporate leaders had been previously warned of the need for more safety and better maintenance at the plant there. Perrow concluded with an analogy to the case of nuclear power accidents, which he said present two levels of reality: the reality on the ground for local exposed people, who experience a great deal of damage, and the reality seen by governments and some nonprofits, which say that radiation levels are too low to be detected and are not a serious health threat. He sees this same situation occurring with the risks of fracking.

Discussant Comments, Roger Kasperson, Clark University

Kasperson is research professor and distinguished scientist at the George Perkins Marsh Institute at Clark University; his research interests have included the vulnerabilities of people, places, and ecosystems and ways to reduce these vulnerabilities and build resilience. He spoke about the issue of social trust and risk. He identified some issues that need further exploration, as there is no literature yet on social trust and risk

in relation to gas exploration. He said that people in government and industry often tell him that trust will not be a major issue because their organizations have good relations with the public. However, he pointed to trends showing a huge decline in public trust in the federal government over the past 50 years and said that the trends are similar for state governments and for corporations. He said that the current, very rapid development of natural gas and the related transformation of our energy system will require a high level of social trust at a time when social trust has sunk very low.

Kasperson said that people now are being socialized into very low levels of social trust. Two decades ago, he said, someone who proposed a new technology would probably get an immediate favorable reception, but now innovators cannot count on trust and must expect suspicion. He cited research by Paul Slovic (1987) indicating that events that might be expected to increase social trust have smaller effects on trust than events that might be expected to decrease it. This evidence indicates that once trust is lost, it is very difficult to regain, Kasperson said, adding that now we need to proceed from high levels of social distrust, which is a new situation in American history.

He noted that concerns about shale gas development occur at scales from local to global and that issues of trust arise at all these levels. He emphasized that uncertainty is dangerous for social trust: the greater the uncertainties, the greater social trust needs to be. He said that the many uncertainties presented by shale gas development create the problem of managing the risks and uncertainties under conditions of low social trust.

Kasperson concluded with several observations. He noted that where those bearing risks lack trust in those making decisions, they demand a greater role in decision making. He said that loss of trust is systemic in the United States. Shale gas, Kasperson said, is like low-level radioactive waste in presenting a very difficult combination of a highly dreaded hazard, large uncertainties, and low social trust. These are conditions that create unusually difficult management and regulatory challenges and call for different kinds of governance processes. He said that the usual methods of risk assessment and command-and-control regulation tend not to work very well when social trust is low.

Questions and Discussion

Questions and comments from participants following the above presentations are summarized here under headings of Krupnick's presentation, social trust issues, climate change issues, and prospects for solutions.

Krupnick's presentation. One participant suggested that Krupnick's idea of cumulative risk assessment leaves out the social part, including community impacts and environmental justice issues, and thought that a different term might be used. He also took issue with the word "accidents," saying that these are incidents and are preventable through stronger safety culture, Krupnick agreed.

In response to a question about Krupnick's surprise that surface water issues were so prominent among experts' concerns, Krupnick replied that he would have expected more concern with ground water than surface water, and possibly more concern with seismicity. He noted that the respondents who described themselves as having the greatest expertise focused particularly on surface water issues related to casing and cementing.

Another participant suggested that expert consensus on the top priority risk pathways, though promising for reaching agreements, may not indicate that those are the most important areas for regulation. He also asked whether agreement on the most important risk pathways implies agreement on how to reduce those risks. Krupnick agreed with the first comment, but noted that each respondent was asked to identify the risks he or she thought most important to address. He said his study had gathered little information on experts' views about how to reduce the risks, though it did ask whether respondents thought industry or government should take primary responsibility. For the consensus risks, industry agreed with others that government should take primary responsibility; for the nonconsensus risks, industry respondents were more in favor of industry taking primary responsibility.

Social trust issues. A participant asked whether distrust applies to all levels of government and particularly, whether local governments still have the public's trust. Kasperson replied that this is highly variable from place to place. Where there are good personal relationships with local officials, levels of trust are sometimes high, but in some instances, trust in federal agencies is stronger than trust in local governments. With energy facilities, both the risks and the levels of social trust are very site-specific.

Another participant commented that in the communities in the Marcellus shale region that she has studied, people seek local action because of mistrust of higher levels. She also noted the increasing incidence of litigation, which does not resolve the mistrust question. Kasperson noted that litigation is particularly typical of the United States and is usually polarizing. With high mistrust, he said, willingness to rely on political systems gets weaker and, in the United States, that often translates into court action in the form of liability cases. Perrow added that people rely

on the courts because they have lost trust, and they hope that a court ruling in their favor will restore trust.

Climate change issues. Perrow expressed pessimism because shale gas provides additional cheap fossil fuels, and 80 percent of fossil fuel resources have to be left in the ground to avoid surpassing average global warming of 2°C by 2050. He sees this industry as speeding the world along the path to global warming by cheapening energy and enabling China, India, and other countries to use more of it. Krupnick said that global warming is being conflated with the risk issues. He said that cheap energy is a good thing: what is not good is the failure to internalize the resulting damage in energy prices. If these damaging consequences are internalized, energy will not be as cheap, but the resource will be good for social welfare. He argued that putting a price on carbon would increase the prices of the highest-carbon energy sources, which would boost renewable energy forms cost-efficiently, without the government "picking winners." The lower social cost of a cleaner fuel will be reflected in fuel cost savings when and if the government implements a carbon tax or other greenhouse gas reduction policy. He said that blaming shale gas for this mismatch of social costs and market price is conflating too much, though there are overlaps.

Prospects for solutions. Susan Tierney asked if anything in the literature or experience can offer guidance for problems like those raised by this set of presenters. Krupnick responded that any industrial activity has this level of complexity and that we have coped with it in the past, adding that this sub-industry is not yet mature, the technology is improving all the time, and many industry actors show good will. He said that we have worked through these problems with the pulp and paper and the chemical industries, and we can work through them in this industry as well, though it has growing up to do. Perrow said he was not hopeful, since this industry has a payoff structure that is worse than that of the chemical industry in terms of the distribution of costs and benefits, and it would be harder to change.

WRAP-UP DISCUSSION OF THE WORKSHOP

At the end of the previous session, workshop chair Mitchell Small asked the participants to think about the risks they consider to be of greatest significance and to identify any of these that have not yet been discussed. For the risks they see as being most in need of further analysis, he asked the participants to consider (a) the state of scientific understanding of the risk, (b) the availability of methods and procedures to address

the risks, and (c) high-priority needs for further data and studies. He distributed a table with a list of risks, organized under the topics of the workshop presentations, and invited participants to present their thoughts during the final discussion. The summary below organizes the participants' comments under headings of mishaps in gas extraction; human health; society-level economic and political risks; ecological effects; waste treatment; management of produced water and water withdrawals; routine air emissions and methane leakage; well design, construction, and quality control; unequal distribution of costs and benefits and community risk issues; and methods of risk analysis.

Mishaps in gas extraction. Small suggested that scientific understanding of these risks is at a medium level; there is a fairly good understanding of what to monitor and what effective responses would be. The problem, he said, is that this understanding may not be uniformly applied across the industry. Although there are methods to reduce risks, the extent of their use is unclear. He identified two issues needing further study: (1) development of sensors on the equipment and for monitoring nearby air and water conditions, wellbore integrity, and so forth; and (2) assessment of the costs of this equipment and its ability to make adequate measurements. He said there is a need for supervisory control and data acquisition systems, such as are used in the water supply industry for integrated data collection, reporting, and real-time adaptive management. He sees this topic as a high-priority area for research because knowledge and methods are developed well enough to be used soon and to identify high emitters early.

A workshop participant questioned the quality of the data on mishaps, saying that in that sense, the level of scientific understanding is low. Warner North of Northworks, Inc., suggested distinguishing between general understanding of the processes in question and local understanding of conditions at particular sites. Roger Kasperson noted that the problems of response systems involve human behavior as well as technology, and Small agreed that even with a good technical warning system, human response systems may be inadequate—especially with warning systems that have high false-positive rates.

Human health. Lisa McKenzie, Colorado School of Public Health, proposed human exposure and health monitoring as a high priority, saying that scientific understanding is weakened by a lack of data and that methods and procedures to address the risks are not well developed. She said that public health is a major issue that is too often left out of the discussion. Other participants suggested adding stress and trauma due to traffic accident mortality and morbidity to the list of health concerns.

Krupnick suggested that statistical studies of historical data are important for understanding health effects of shale gas development activities and for identifying health issues needing further study. In response to a question about whether there are biomarkers that could provide indicators of extended exposure, a participant said that the U.S. Department of Health and Human Services has conducted biomarker studies, with data available for analysis, and that the Occupational Health and Safety Administration's monitoring of workers might also be used for comparisons with nonworker populations.

Society-level economic and political risks. Susan Tierney raised a complex of issues around climate change, fuel substitution, and energy use, related to social, political, and economic risks connected to the ways policy on shale gas is made. She said that rapid shale gas development, negative impacts and community dislocation, and debates about development of renewable energy versus shale gas could lead to large amounts of stranded investments and locked-in greenhouse gas emissions. She said that scientific understanding of this complex of issues is low and suggested that better elucidation of the risks can help inform the public in dealing with them. In response to a participant's question, Small noted that this issue concerns risks to the economy, which need greater understanding and require integration of social and ethical considerations, which affect human behavior. Newell added that there are a number of unanswered questions about how different relative prices will affect fuel substitution and other economic processes and proposed that increased understanding of the complex effects of policy actions on the larger economic system are important for informed choice.

Ecological effects. One participant identified ecological impacts, such as habitat disruption, as needing attention. She rated the state of scientific understanding as medium for some habitats and low for many others, and she saw the availability of methods to address the risks as medium to low, depending on the habitat. This participant proposed that major research needs include understanding thresholds for change, conducting landscape-level analyses, and exploring the ability of restoration to mitigate disruption of natural habitats, partly using controlled experiments. Aida Farag identified air and water toxicity as topics affecting ecological risks and suggested that scientific understanding is at a medium level for salt and low for trace organics. She said that methods are available to address risks, but their economic costs are unclear. She would give this area high priority for research on thresholds of change, first in the laboratory and then in the field, with monitoring related to species-specific impacts and restoration planning. We may know *what* needs to be done

for mitigation and remediation of ecological impacts, she said, but we don't know *how* to do it.

Waste treatment. Perrow said that industry knows how to use returned water, but he sees a serious problem in the lack of knowledge about treatment and disposal of radioactive materials and other waste constituents. This suggests a need for studies of treatment methods. Another participant said that there are technologies available for treatment and that some are in use in the Marcellus shale region, although there is a need to reduce treatment costs.

Management of produced water and water withdrawals. Abbas Firoozabadi of Reservoir Engineering Research Institute and Yale University suggested that reinjection of produced water into deep formations was a promising risk management technique, adding that with very deep injection, seismicity risk is much reduced. There was some discussion of the ability of the tight deeper formations to accept this water. Jean-Pierre Nicot expressed the view that injection of produced water, at least in Pennsylvania, is a regulatory problem, not a geological one.

Nicot raised the issue of water withdrawals and said that much is known about water needs, though in some places companies may have to be required to report their withdrawals. He said there is a need for better understanding of the availability of subsurface brackish water for use in shale gas extraction operations. Regarding water leakage, Nicot said that monitoring is made difficult by the lack of knowledge about the mechanisms of leakage and that this problem applies not only to shale gas. He identified needs for better understanding of the subsurface behavior of the chemical additives used in extraction and for developing tracers for identifying leaks.

Routine air emissions and methane leakage. A participant said there is good understanding of the mechanisms producing emissions, but very poor understanding of what is happening in the field: for example, is the issue one of good versus bad operators, or is there a manufacturer who is making poorly performing products? He suggested that data are needed on a large number of operations. Tierney added that the frequency of leakage in local distribution systems is also poorly understood. Krupnick said there is good scientific understanding of most of the chemical relationships producing emissions, as well as of how to control them; he suggested that reducing them is mainly a governance issue.

On the subject of local air toxics, a participant said that Texas has much more extensive data than other states but there are still questions about what the air toxics are, how they are distributed through the air,

and how current levels compare to those prior to development. Outside Texas, the state of knowledge is poorer. She said that monitoring technologies exist to measure environmental levels, though making them more affordable may require collaboration between communities and industry. Monitoring should be given high priority, to inform people of the health risks to which they may be exposed, she continued, and biomonitoring can be done along with environmental monitoring, when there have been expressed concerns. She said that improved standard procedures on site and improved communication with the community will help address this issue.

Gabrielle Petron disagreed with Krupnick, saying that the level of understanding of ozone emissions is not very good. She said that Utah has been spending $2 million per year for the past 2 years to understand where winter ozone emissions are coming from, while Colorado has been struggling with ozone in the Front Range since 2004 and is not close to fixing the problem, which comes 55 percent from oil and gas. The area has been in nonattainment since 2007 [of EPA recommended ozone levels]. She expressed distrust in the numbers that some people present, based on the experience in Colorado of spending years to understand the issue without success. She said that although ozone levels can be measured very well, different kinds of measurements are needed to know how to mitigate it. Texas is doing well with monitoring, she noted, but many communities elsewhere do not have the support to do this. She referred to a recent report from the Office of the Inspector General on the low quality and limited quantity of data EPA uses to model emissions. She sees an emergency need for states to monitor their air quality better in order to understand exposures.

Petron also commented on the very different views of the state of knowledge from economists, engineers, and people on the ground. Krupnick said his understanding comes from air quality models that are commonly used. Petron responded that those models were developed for urban emissions, but the needed measurements and monitoring are lacking for rural shale gas development. She added that Western Colorado will soon be in nonattainment because of ozone emissions from Utah, which Colorado cannot control. Krupnick agreed with her position that states need to work together, especially if ozone standards are improved.

Well design, construction, and quality control. A participant accepted Nygaard's claim that the industry knows how to do well design and construction right but said that that doesn't mean it is getting done. Site-specific data are not available. Although methods exist for mitigating the risk, there is neither enforcement nor documentation, governance is not consistent, and no one knows whether well quality control is being done.

Unequal distribution of costs and benefits and community risk issues. Jacquet said that there is fairly good understanding of this issue, as well as of methods to address it, but there are governance issues. He said that further research is needed to develop frameworks and best practices for lessening the unequal distribution of costs and benefits. Another participant pointed out that communities do not always have the authority to undertake plans that would help them; they also may not have access to the knowledge that could support good planning. He advocated an extension-service capacity to give communities access to the knowledge about the impacts they face. Jacquet agreed that most communities have neither the data nor the planning capacity to use it.

Small said that the nation is in the midst of a large-scale adaptive management process but lacks adequate data collection. He suggested that there should be studies in some communities to assess different processes for cost sharing. Jacquet added that we know how to do such studies. Christopherson said that information is lacking on some kinds of communities that will be affected, particularly suburban and urban communities, including information on their governance capacity. She judged the level of scientific understanding to be low on differences among communities and on the distribution of costs and benefits because of incomplete knowledge of who owns the land and the full costs of development.

Simona Perry offered the judgment that we do not understand community impacts very well and said that long-term research is needed on psychosocial stress at the community level. She noted that the various risks discussed under the headings of community, health, ecological, and water risks are all related to each other and hard to separate. Qualitative ethnographic and historical studies are needed in communities, she said, to understand stressors and inequalities in relation to past experience. Perry said that economic and census data can help with historical analysis and noted the potential of community-based participatory research for addressing inequality of costs and benefits. She believes there is only low to medium understanding of community trust, but there are methods for mitigating the risks, such as using more collaborative community forums and decision processes, as opposed to the usual approach of private decisions by landowners.

Methods of risk analysis. Thomas Webler referred to the *Understanding Risk* report, which recommended that understanding be developed with the stakeholders (National Research Council, 1996) and contrasted it to the focus in this workshop on what the scientists know. He said the workshop is missing what stakeholders and the public know and understand, and he suggested that the project consider what it takes to

engage with stakeholders in discussion of the risks, as *Understanding Risk* recommended. He also commented favorably on the presentation from RFF, which emphasized cumulative and synergistic risks and said that in addition to considering particular kinds of risks, their interactions need to be kept in mind.

Final Comments

Small invited presenters and participants to offer summary comments. He reminded all participants that the workshop project is intended not to develop recommendations but to clarify the state of knowledge. Paul Stern commented briefly on the risk governance workshop scheduled for August 15-16, which was designed to address how risk reduction could be made to happen, given what is known about governmental and other approaches to identifying and disseminating best practices.

Tierney reported on various comments from Webcast viewers of the workshop in Pennsylvania who were quite vocal about wanting the shale gas development stopped. North said that he hoped the NRC would remain open to ideas from people living with shale gas development. He endorsed the suggestion that the kind of analysis being discussed at this workshop should lead into an analytic-deliberative process of the kind defined in the *Understanding Risk* report. He expressed the hope that the governance workshop will distinguish between risks that arise when best practice is not followed and the larger problems of risk planning and coordination, which are where an analytic-deliberative process ought to be applied. Small noted that input from the Webcast viewers can point researchers toward doing "the right science," as *Understanding Risk* put it. Finally, Perry referred to a paper she recently published on the use of an analytic-deliberative process in shale gas development (Perry, 2013). She noted that such a process can be difficult because of transparency issues that need to be overcome and the need to engage the industry in the process, as well as people who may be affected.

Wrap-up of Risk Questions for Future Analysis

This section provides the rapporteur's comments on trends and patterns that emerged during the presentations and discussions. One such pattern indicates that considerably greater analytic attention has been given to some of the risks related to shale gas development than to others. The risk domains that appear to have received the greatest attention—based on this workshop—include effects on water systems, seismicity, and methane leakage from wells. The domains of potentially significant risks that, based on presentations and comments from various participants,

have not been as carefully examined include risks to public health, ecosystems, air quality, human communities, and global climate.

Research questions that were posed by one or more workshop participants are summarized below under the topics of risks to public health, ecological risks, risks to air quality, risks to communities, implications for climate change, risks to water resources, and other risk issues.

Risks to public health. Several workshop participants argued that strong epidemiological studies about the public health effects of shale gas development appear to be lacking. Key research needs identified by one or more participants include studies to: (1) estimate toxicity factors for substances used in shale gas development; (2) measure exposures to toxic substances and other health stressors and describe variability in emissions and exposures; (3) track the health of workers and residents near shale gas operations; (4) understand the effects of chemical mixtures, noise, traffic, and other stresses on health and quality of life; and (5) incorporate stress into individual and community-level health assessments. Several participants emphasized that systematic before-during-after data collection is especially needed on exposures and health outcomes. Region-specific studies were also highlighted by several presenters and participants as particularly important.

Ecological risks. Studies of the ecological effects of shale gas development activities appeared to a number of participants to be at a very early stage of development. Key research needs identified by one or more participants and presenters include (1) assessments of effects of different patterns and degrees of surface disturbance on terrestrial and aquatic species, (2) studies defining mechanisms of species responses (e.g., toxicity, avoidance, reproductive disruption), (3) field studies of thresholds of change for different species and groups of species, and (4) research to model ecological impacts and studies of restoration methods.

Risks to air quality. Research needs identified by one or more workshop participants include studies based on actual measurement of air constituents before, during, and after drilling activities; studies defining emissions signatures from shale gas formations; studies measuring atmospheric fluxes of methane, particularly in urban areas; characterization of silica emissions; measurements of emissions reductions from best management practices; and development of scalable leak detection methods.

Risks to communities. Several participants noted that there have been very few studies of effects of shale gas development on communities. Among key research needs that one or more participants suggested are

studies of: (1) the distribution of new wealth and the effects of different distributions on community processes, (2) the magnitudes of stress, (3) effects on communities indirectly affected (e.g., by materials transport), (4) effects on urban communities experiencing gas development, (5) the long-term development implications of different patterns of shale gas development, (6) effects on pre-existing industries, and (7) the community effects of possible best practices in development.

Implications for climate change. Most analyses of this issue, according to several of the participants, have been narrowly focused on issues of fuel substitution in the electric power sector and methane releases. Key research needs that one or more workshop participants suggested include studies of the effects of low-cost gas on aggregate demand for fossil and renewable energy sources, studies on fuel switching in the industrial and commercial sectors, studies on the emergence of renewable energy supplies, and studies on the pattern of energy use in the economies of developing nations. Analyses of the implications of various energy policies on these relationships were also identified as important.

Risks to water resources. Some participants identified as research needs studies estimating the degree of stray gas contamination of water wells and the long-term effects of shale gas operations on water quality and availability.

Other risk issues. Some workshop participants identified a need to better understand the distribution of risks and benefits from shale gas development and the risks that shale gas development may pose to trust in various social institutions.

Workshop 2

Governance of Risks of Shale Gas Development

The purpose of this workshop, conducted August 15-16, 2013, was to identify the range of concerns that have been expressed about the management or governance of the risks unconventional shale gas development may pose and to consider the ability of a range of institutions and actors, both public and private, to manage those risks to the satisfaction of the various interested and potentially affected parties in society.[1] The first day's presentations and discussion focused mainly on governance by government agencies at various levels; the second day expanded the discussion to include industry self-governance, public participation processes, public-private partnerships, and other governance approaches.

Meredith Lane, director of the National Research Council (NRC) Board on Environmental Change and Society, opened the workshop by describing the work of the board, which oversees the project that includes this workshop, thanking the sponsors of the workshop, and mentioning some recent and ongoing projects related to shale gas development at the National Academies. She acknowledged the many positive economic and other implications of increased abundance of natural gas but pointed out that the focus of the current project is on the risks of this technology. She introduced the members of the steering committee that organized

[1]The agenda for this workshop, the speakers' abstracts and slide presentations (in PDF format), and video archives of the presentations and discussions are available at: http://sites.nationalacademies.org/DBASSE/BECS/CurrentProjects/DBASSE_069201 [July 2014].

the workshop and emphasized that the summary report will not contain any conclusions or recommendations of NRC-sanctioned entities, including the steering committee or the workshop as a body. Any judgments, conclusions, or recommendations are strictly those of the individual participants who offer them.

Workshop chair Mitchell Small provided an overview of the agenda and the workshop procedures. He briefly summarized the range of risks examined at the first workshop and explained the purposes of this workshop: (1) to assess current and evolving approaches to shale gas governance in the United States, also seeking insights from other countries; (2) to identify the state of knowledge on the performance of various governance approaches, considering the possible roles of, and coordination among, federal, state, and local governments, industry self-governance, and involvement of communities and nongovernmental organizations; and (3) to consider specific initiatives proposed to improve the scientific and social basis for the governance of shale gas risks.

Small emphasized that the tone of the workshop is investigative. He encouraged participants to recognize that knowledge in this domain is rapidly evolving and that final answers are not in hand and to maintain a tone of searching for improved understanding. He said that the workshop would be deemed successful if it clarifies the current mechanisms and state of knowledge related to risk governance of shale gas development, if it identifies potential enhancements to risk governance mechanisms and the information needed to evaluate them, and if workshop attendees come away with new insights and contacts to help them better understand and consider risk governance options. He also noted that the intended products of the workshop would include a published workshop summary and a collection of papers for a peer-reviewed journal.

IDENTIFYING GOVERNANCE CONCERNS AND CHALLENGES

The workshop's opening session considered governance concerns from three perspectives: (1) responses to a broadly based elicitation of concerns from a cross-section of interested individuals, (2) an analysis of the current governance system in the United States, and (3) an examination of the kinds of industry operations that might require management or governance.

Responses on Shale Gas Governance from a General Elicitation, Presentation by Gabrielle Wong-Parodi, Carnegie Mellon University

Wong-Parodi is a research scientist at the Center for Climate and Energy Decision Making in the Department of Engineering and Pub-

lic Policy at Carnegie Mellon University. Her research interests include applying behavioral decision research methods to issues of environmental sustainability. She reported on the governance concerns identified in the general elicitation described by Thomas Webler at the start of the first workshop. The open-ended elicitation produced 531 responses (21% of all responses) that dealt with issues related to governance. These responses fell into six broad categories:

Corporate culture and practice. Some respondents saw the industry as cutting corners out of greed and a search for speed. One said that "new animal farms and wind farms are required to conform to standards that are not being applied to oil and gas companies. . . . How did money become more important than people?" Some saw the industry's growth as leading to rapid and even dangerous development. Some respondents voiced fears of illegal activity, corruption, and bribery, including payoffs to landowners and politicians. Some were concerned with activities that are legal but morally objectionable, such as intimidation of landowners and communities through "legal bullying." Some were troubled by the ability of the industry to leverage power—for example, through political lobbying.

Regulatory shortcomings. Some respondents questioned the adequacy of existing regulations and industry exemptions from federal regulations and laws, with many citing the so-called "Halliburton loophole," which leaves regulatory responsibilities that are federal for other industrial activities to the states in the case of hydraulic fracturing for shale gas extraction. Some people questioned the enforcement capacity of regulatory authorities, citing lack of time, expertise, and financial resources as constraints.

Inadequate information. Some concerns related to a lack of data or of relevant data; some to flawed, biased, or limited science. Some respondents were concerned about dissemination of false information, and some questioned whether industry is sharing only information that favors its objectives or said that industry is willfully making it hard to understand information. One respondent said there were "too many obstructions to collecting and/or publicizing hard data about most impacts. . . . Many of these obstructions are a result of nondisclosure requirements imposed by the oil and gas industry. Even doctors are forbidden from reporting health impacts that they have been involved in treating."

Unfairness of legal systems and regimes. Some respondents were concerned with a lack of accountability for industry and with the legal liabil-

ity of landowners, should something go wrong during gas development. A representative concern in this category was with "compulsory integration, which takes gas from under my property without my permission and then holds me liable for damages that may occur to my neighbors."

Distributive and environmental justice. These concerns focused on the distribution of risks and benefits from shale gas development at spatial scales from local to global. There were, for example, concerns about wastes being transported across state lines to states and communities that do not want them.

Inadequate public participation. Some respondents complained about decisions being made without adequate public consultation. Some noted that decision making was hampered by polarized views, which some respondents blamed on the industry.

These concerns raise three broad themes, Wong-Parodi said. One concerns science: the perception that there is an insufficient level of scientific understanding to make well-informed decisions and a lack of transparency in formulating and disseminating new knowledge. A second is trust: some respondents do not trust existing institutions to protect people and the environment from shale gas development risks. The third is justice in the distribution of risks and benefits and in decision-making processes that affect individuals, communities, nations, and future generations. Wong-Parodi concluded by saying that her research group is not claiming that all these concerns and claims are demonstrably true, only that these three underlying themes all deserve consideration in shale gas development.

Governance Concerns and Government Capacity, Presentation by Barry Rabe, University of Michigan, Ann Arbor

Rabe is J. Ira and Nicki Harris family professor of public policy, Arthur F. Thurnau professor of environmental policy, and director of the Center for Local, State, and Urban Policy at the Gerald R. Ford School of Public Policy, University of Michigan, Ann Arbor. His research interests include intergovernmental environmental policy development and implementation. Rabe offered some overview comments on governance issues. He began with the classical governance questions posed by Aristotle: Who governs? How do they govern? And what are the results? In respect to these questions, he said, shale gas development is quite unlike established governance arenas such as education or management of the national parks. With shale gas, there has been very limited scholarship on gover-

nance and few congressional hearings to consider the governance issues. According to Rabe, the governance system for shale gas is decentralized, with a federal role but with most of the power held by states and local governments, partly because of statutory exemptions from some of the federal laws. Although the federal government could take strong control, he does not see this as likely at present.

Rabe suggested that a constrained federal role may create interesting opportunities for states, localities, and industry organizations to develop new roles in governance. States are largely on their own, he said, although many have legacy statutes for dealing with oil and gas that provide bases for governance, and new statutes are being proposed. Shale gas raises long-standing questions about the implications of moving from federalized to more decentralized governance, he continued, and there are two competing views on this decentralization. One view posits a race to the bottom: states in a competitive political economy aggressively go after the resource, trumping environmental protection and creating regulatory capture. The other view suggests that states will race to the top through innovative approaches to governance, integrating regulation of media such as air and water, developing improved mechanisms for transparency and public engagement, developing performance metrics and new policy tools, collaborating across boundaries and across agencies, sharing information and staff, and engaging local governments. The outcome of competition between these two views is not settled, Rabe said.

He then commented on several generic issues as they apply to the case of shale gas: state and local capacity, trends in partisan control of state government, the expanding role of state legislatures in fashioning statues, and diffusion versus heterogeneity in policy development.

State and local capacity. A number of states get severance taxes from shale development, but many put none of that revenue into shale gas governance, Rabe said. The last 4 years have seen the steepest drop in state and local government employment in the past 50 years, he noted, with 1.1 million jobs lost. Yet a shale gas governance system will require outstanding, sophisticated individuals to implement it. Thus, Rabe concluded, capacity is a challenge, though no two states are the same.

Trends in partisan control of state government. During the past 35-40 years, Rabe said, innovation in state-level governance has mostly come when there has been cross-party competitiveness at the state level. More recently, states are shifting back to a pattern of single-party control of state government, he continued, adding that it is too soon to tell, but this shift may create difficulties for state-level governance.

The expanding role of state legislatures in fashioning statutes. There has been rapid growth recently in the number of state legislatures considering bills on shale gas and in the number of laws passed. Rabe said that this creates a moving target for policy analysis and increases the possibility of legislative, rather than administrative, decision making.

Diffusion versus heterogeneity in policy development. Governance strategies could diffuse slowly from state to state or could show a pattern of heterogeneity, with a very wide range of state responses, Rabe suggested. Some states are starting to develop mega-statutes, which create radically different governance approaches in different states for dealing with the same issues, over a short period of time. This heterogeneity could reflect different geological realities or other drivers. Terms like "best practice," "excellence," and "world-class" are being used frequently as adjectives to describe policies, he said, but in fact we do not have a good way of evaluating governance regimes.

Governance Considerations from a Technical Perspective, Presentation by Mark D. Zoback, Stanford University

Zoback, who addressed the workshop via telephone, said that he has been working with the industry on the problems of extracting shale gas resources, which are geologically challenging to extract, in an economically viable and environmentally responsible way. He noted that shale gas development is a large-scale industrial process that presents a diversity of challenges in terms of environmental impacts, impacts on communities, and so on. He referred to a new paper (Zoback and Arent, 2013), which discusses the technical challenges associated with shale gas development under the categories of community, land, water, and atmospheric issues. He described his knowledge as mainly about issues below the earth and said that people need to be concerned about the adequacy and enforcement of regulations in these areas. In Colorado, there are 50,000 active wells of all types and 15 regulators. This creates concern about the adequacy of regulation and enforcement. The new paper makes a number of points regarding the potential benefits of switching from coal to natural gas, including benefits to public health (for instance, there are said to be 1.25 million annual deaths in China attributable to burning coal). But to realize the benefits, effective environmental safeguards are needed.

Zoback's comments drew heavily on the 2011 report of the Secretary of Energy Advisory Board on shale gas development, on which he served (Secretary of Energy Advisory Board, Shale Gas Production Subcommittee, 2011). The report concluded that shale gas can be developed in an environmentally responsible manner and offered 20 recommendations on

how to do this. Zoback focused on four of the recommendations, which bear on governance issues.

Two recommendations were for full disclosure of the composition of drilling, hydraulic fracturing, and flowback fluids and full manifesting of drilling and fracturing fluids and what happens to them. Disclosure requirements vary greatly across states, Zoback noted, both in whether and what kinds of disclosure are required. He endorsed the industry's FracFocus Website as a good thing, but said it is only the beginning of what is needed.

The third recommendation was for the creation of regional centers to address issues such as finding optimal ways to minimize the cumulative impacts of shale gas development. Very little of this has been done, Zoback said, but the new Center for Sustainable Shale Development (CSSD) in the Marcellus shale region is a step forward. It is also seeking to establish company-level certification. Zoback said that well-site activities should be certified, as well as the companies that carry them out, with certification based on actual inspection at the well site.

The fourth recommendation was for sustained research support for continual improvement of resource recovery and environmental protection. There has not yet been much progress on this, he said.

Zoback also commented on well construction, aquifer contamination, and methane leakage. He sees governance of well construction as a major issue and cited the Resources for the Future (RFF) research on experts' risk judgments (presented by Alan Krupnick at the first workshop) as indicating a high level of experts' concerns, regardless of who employs them, with cement, casing, and impoundment failures. The first two are intrinsic elements of well construction, as are several of the less-frequently named concerns. These concerns led to a recommendation in the Secretary of Energy Advisory Board report for adopting best practices in casing, cementing, and pressure management and for pressure testing to confirm that well construction has followed best practices and is adapted to local geological conditions, with multiple barriers to contamination or leakage from the well casing (Secretary of Energy Advisory Board, Shale Gas Production Subcommittee, 2011). Zoback said that requirements for cementing vary greatly across states, but do not generally include requirements for multiple barriers. In addition to prescriptive regulations, Zoback advocated performance-based regulations to ensure the needed protection. He believes that many companies are taking these issues seriously and doing the right thing, but he said it is necessary for all companies to do so.

On the issue of leakage, Zoback said that, to his knowledge, the best study was done at the Joint Institute for Strategic Energy Analysis at the National Renewable Energy Laboratory. It asked whether unconventional

gas extraction is intrinsically more prone to leakage than conventional gas extraction and found that life-cycle greenhouse gas emissions from natural gas, whether conventional or not, when used for power generation, were about half those from coal. This study made measurements only in the Barnett shale, Zoback noted, so may not apply to all gas basins. Although that study's message was that shale gas wells are being developed in ways that have greenhouse gas benefits, Zoback said that more studies need to be done. He added that attention to the leakage issue is a good thing because those leaks need to be addressed. He concluded by saying that the governance issues from a technical perspective are multifaceted and challenging.

Questions and Discussion

Two participants asked about the elicitation process on which Wong-Parodi reported. One asked about selection bias in the process. Wong-Parodi replied that the goal was not to get a representative sample of the public but to identify concerns of interested and affected parties. Her team reached out to a variety of organizations that hold different positions on shale gas development, including industry groups, in a process that probably selects for people who want to voice concerns. Another participant asked if the elicitation provided any insights from the industry respondents or from regulators about what was wrong in governance and how it can be improved. Wong-Parodi replied that the elicitation did not request recommendations for governance.

A Webcast participant asked whether, given that shale oil and gas are nonrenewable resources on human time scales, the phrase "sustainable shale development" in an organization's name is disingenuous and a reason for some people's distrust of the fracking industry. Zoback said this is a legitimate point, but in his view, shale gas is a transition fuel to a sustainable energy system—a very good first step in getting away from coal and decarbonizing the energy system, though only a step.

THE ABILITY OF GOVERNMENTS TO MEET GOVERNANCE CHALLENGES

A series of presentations and discussions during the first day of the workshop focused on the ability of governments at various levels, in the United States and other federal systems, to develop and implement regulations and other control systems to address the risks of expanding unconventional oil and gas development and to coordinate their efforts. This focus included ways to improve this ability.

Evaluating and Enhancing the Capacity of the States to Govern Unconventional Oil and Gas Development Risks

Presentation by Hannah Wiseman, Florida State University

Wiseman is an assistant professor in the Florida State University College of Law. Her research examines the role of regulation in environmental protection from sublocal to national levels. She began by noting that her presentation was mainly descriptive and did not attempt to discuss broad issues such as whether there is a race to either the top or the bottom among states in their regulatory activities. Description is much needed, she said, because this domain is so complex, with multiple kinds of technologies and risks, and therefore multiple regulatory codes in any single state.

She said that any analysis of risk governance must identify the risks, who is involved in governing them (including industry), what the substantive controls are (including gaps in them), and how well governance is doing. Her comments focused mainly on the upstream side of the industry, but she noted the increasing importance of other stages of its life cycle, including distribution and export, and the connections among the stages. States have been important in identifying the risks, Wiseman said, because state inspectors visit sites and document a range of problems, particularly including spills from equipment onsite. However, she added, it is possible that state inspectors are mainly identifying the kinds of risks they are used to looking for, while missing others.

Data needs. Better understanding of the risks requires better production of data. Industry collects some data, but much more is needed, Wiseman said. States' data requirements lack uniformity. As examples, she cited Ohio, which requires well operators to sample all water wells within 1,500 feet of proposed horizontal wellheads, and Colorado, which requires initial baseline samples and subsequent monitoring of a maximum of four water sources within a half mile of a proposed well site. Different states also require testing of different water constituents. Wiseman suggested that governance may benefit from more uniform agreement on what to test for.

Substantive controls. The key governance questions, according to Wiseman, are the substantive controls and which institutions are responsible for them. Regarding federal regulations, industry spokespeople think there are a lot, but others point to some key exemptions. States' roles include developing their own regulations and implementing federal ones; there are also local regulations. Within states, there may be multiple agencies with regulatory authority, with different distributions of authority in

different states. The key, Wiseman continued, is whether all the agencies in a state, taken together, have the authority to do the needed governance. She noted that regional governance involving several states may also be needed for some purposes and that there may be issues of communication not only between states but also among agencies within a state—for example, between the agencies that notice a problem and the ones with the authority to regulate it. She added that private governance is also important; for example, the financers of shale gas operations and the leasers of mineral rights sometimes put environmental provisions into their agreements with operators. Overall, Wiseman said in summary, although federal and state agencies both have areas of control, states have much of the control in shale gas regulation. They vary greatly in the kinds of regulations they impose (e.g., prescriptive vs. performance-based) and in their content.

States' capacity. Wiseman noted that because state regulations vary greatly and change often, entrants into states may not fully understand the regulatory environment. States may need to make educational efforts to train entrants on what the rules are. But because companies do not always follow the rules, regulatory capacity is important. Many states have very few regulators per well (Wiseman presented data indicating that several states have on the order of one regulator per thousand wells). This may not be a telling statistic, she added, because regulators are needed mainly at certain points in a well's life cycle, and some states report a very large number of inspections per inspector. In fact, only a few states have tried to determine the number of inspectors they need to regulate the industry, said Wiseman, and states vary greatly in how often inspectors are required to visit a site, whether or not they allow random inspections, and other regulatory practices. Data on violations and enforcement indicate very great differences among states, both in the number of violations found per inspection and in the number of enforcement actions taken per violation. (To illustrate these differences, Wiseman pointed out that Texas reported a much higher proportion of violations per inspection than Pennsylvania but a much lower number of enforcement actions per violation.)

States also vary greatly in what inspectors' reports cover and in inspectors' qualification and training levels, Wiseman said. They also vary in what penalties they require for violations, how much discretion they allow in setting penalties, and which violations are prioritized for enforcement. This situation can make things difficult for industry, she noted, which wants predictability and fairness in inspections. It also raises questions about whether there is enough enforcement to deter violations and ensure remediation.

Wiseman concluded by suggesting that the federal government can help by providing databases on regulatory and enforcement policies and that increased state fees for permits could solve a lot of staffing problems at the state level.

Discussant Comments, R. Steven Brown, Environmental Council of the States, Washington DC

Brown, who was executive director of the Environmental Council of the States (ECOS) at the time of his presentation, reported on a very diverse meeting that ECOS held in July 2013. The meeting included representatives from many states, from insurance companies (which have an interest in limiting damage), and from environmental groups and engineering firms. The meeting identified several issues states are experiencing. One is the diversity of contexts for gas development, which is urban in Texas but completely rural in North Dakota. Impacts are also diverse. For example, states that have had drilling for a long time report that impacts at well sites are hardly noticeable because agencies are already well prepared to deal with these issues.

Not all the impacts are environmental, Brown said. The ECOS member in North Dakota, for instance, was most worried about social impacts caused by in-migrants who do not have the same relationship with the land as native North Dakotans and have different attitudes because they will be there only temporarily. For Minnesota, where there is no fracking, Brown said the concerns expressed at the meeting were with fracking sands transported across the state, which causes traffic and other disruptions. Rapid change was also an issue raised at the ECOS meeting; in Colorado, rules had to be promulgated in less than a year.

States seek information from their peers, and Brown expects that convergence is likely to occur over time. Multiagency relations were also an issue: environmental, natural resource management, and oil and gas agencies all tend to be involved. The ECOS members, which are the environmental agencies in their states, are not necessarily the lead agencies in the state on shale gas. In closing, Brown said that support from the federal government is really key for the states, especially for support of science research.

Presentation by Jim Richenderfer, Susquehanna River Basin Commission, Harrisburg, Pennsylvania

Richenderfer, senior scientist and acting chief of the Water Resources Management Division at the Susquehanna River Basin Commission (SRBC), described the SRBC, whose members represent Pennsylvania,

New York, Maryland, and the federal government, as having authority to regulate water allocation in the basin. He emphasized the need to manage a system like a river basin on a holistic scale, recognizing that its hydrological boundaries are more important than political boundaries. He noted that the Delaware River Basin Commission, which was formed before the U.S. Environmental Protection Agency (EPA) was created, has jurisdiction over water quality issues, which SRBC does not. However, SRBC is interested in water quality, and half its staff is involved in water quality monitoring.

He noted that since 2008, about 4,000 unconventional gas wells have been drilled in the Susquehanna basin, of which about 2,400 have been hydraulically fractured to date. For SRBC, the amount of water consumed is less important than the locations from which it is drawn. Shale gas development has so far used about 11 billion gallons of water, Richenderfer continued, which is less than half the water the river delivers daily to the Chesapeake Bay. However, most of these withdrawals are in the upper reaches of the basin, where the majority of the basin's exceptional-value and high-quality streams—the valuable recreational waters—are located. The commission's objectives, according to Richenderfer, are to stay out of the way of the shale gas play while also protecting the resource.

Richenderfer said that the amount of flowback water has been far less than originally anticipated: an average of 4.4 million gallons of water is used per frack, and 10 percent or less of this returns as flowback. From a basin perspective, the resource can be managed as a hydrological unit with basin-wide monitoring programs, as is done with the nuclear power plants, which consume so much water that the commission has to consider flow augmentation during low-flow periods to protect aquatic ecosystems. A basin-wide approach allows the storage of water to release during drought to serve consumptive uses. Richenderfer noted that governance approaches need to include interstate approaches that reflect the natural systems to be protected. SRBC has changed regulations four times in the past 5 years, he said, adding that the commission believes its approach is more flexible than that of most states.

Questions and Discussion

The various questions and comments by participants and presenters during this discussion period are summarized here under the topics of heterogeneity among states, interstate issues, capabilities of state officials, basin-level issues, federal roles, multimedia issues, and trust issues.

Heterogeneity among states. Alan Krupnick noted that the RFF database is publicly available in RFF's *State of the States* report, which examined

several alternative explanations for the differences in the number of regulations of oil and gas, the types of regulation (e.g., command and control versus performance standards versus permitting), and the stringency of the regulations where regulations are quantitative. The report indicates that the heterogeneity was not well explained by any of these variables, said Krupnick; for example, factors such as the political party holding the governorship do not explain much. Rabe added that such research could address other issues, such as whether there are severance taxes and the kinds of incentives these taxes and their use create for actors in the industry.

Brown noted the rapid change in funding: 80 percent of the funding of state agency work on shale gas comes from fees, compared with 40 percent 10 years ago and only about 5 percent a few years before that. He said that many states have been able to continue regulation only because of fees, adding that this mechanism makes it necessary to go back to the legislature repeatedly to ask for new fees when expenses increase, which is hard to do effectively. Other comments indicated that in some states, fees have been "raided" for use in the general fund and that there is great variation among states in income from fees. Wiseman said that the highest fees may be in West Virginia, which charges $10,000 per horizontal well, while some states' fees are only $500. She added that Texas hasn't updated its fees for about 10 years.

Interstate issues. In response to a question about how states that do not have active shale gas drilling are handling impacts that cross state boundaries, Wiseman cited flowback water from Pennsylvania flowing into Ohio as an interesting case. She said the U.S. EPA has been involved in this, trying to make sure that Pennsylvania wastewater is not sent to treatment plants in Ohio. She added that interstate compacts do not always work, mentioning nuclear waste disposal as an example of a failed compact. She concluded that regional governance agreements need ongoing attention to be effective, and they may require involvement of local governments, too. Brown added that interstate relationships are sometimes informal. Susan Tierney asked why more states are not asking for a review by STRONGER (State Review of Oil and Natural Gas Environmental Regulations, a public-private partnership organization). Wiseman said that more needs to be known about the extent to which states are implementing the guidelines developed from STRONGER. She suggested that some states may be hesitant to invite a national partnership group to assess their regulations against a national consensus standard.

Capabilities of state officials. A question was raised about the training status and educational levels of state staff doing the monitoring. Wiseman

responded that she has not researched the training issue and is only aware of the West Virginia requirement that staff have at least 2 years of experience in the industry, but she agreed that this seems to be a significant issue. Brown agreed and added that state staff members sometimes move to take positions in the industry, but when this happens, he said, they at least know the state's rules.

Basin-level issues. A participant said that not all basin commissions work well and asked how the SRBC members are appointed in ways that get them to cooperate. Richenderfer said that the governors and the President appoint the commissioners, who are usually the state environment secretaries and the appropriate official from the Army Corps of Engineers. The staff reviews applications and makes recommendations to the commissioners, who take action quarterly. He noted that SRBC has a challenge with funding, which comes from the four jurisdictions represented in the Susquehanna River Basin Compact. To meet the challenge, SRBC charges fees for water withdrawals, resource surveys, and other things it does.

In response to a question about basin-level water storage facilities, Richenderfer said that some already exist in the Susquehanna Basin, developed by the Army Corps of Engineers, and that SRBC gets input into how those reservoirs are managed. He said that SRBC is also looking at underground mine pools, some of which may have good water quality and can be released in low-flow periods.

Federal roles. A participant from U.S. EPA asked for more suggestions on helpful federal roles. Wiseman responded by saying that a top priority should be to provide a database into which states could put data and to monitor and organize the database to make the data useful. The federal government might also collect the emerging science into an accessible form, possibly organized by risks and state of development, she suggested, and it could also continually assess areas where there appear to be large or interstate impacts and consider the need for changes in regulations.

Multimedia issues. Workshop chair Mitchell Small asked if there are examples, perhaps from SRBC, of efforts to deal with the fact that shale gas is a multimedia problem, affecting not only watersheds but also airsheds, "traffic-sheds," biomes, etc. Richenderfer replied that SRBC has been careful to stay within its own responsibility. Brown said that at the state level, agencies with different responsibilities do commonly work together, often informally.

Trust issues. A participant noted that with some energy facilities, there are governance vehicles that look at multiple effects of development and are quite transparent, but that with shale gas development, there is a tension between a business model that encourages being very quiet (some call this "speed and greed") and the experience of communities that have been surprised by events and did not know where to turn among government agencies. She asked if there is a governance model that addresses the need for mechanisms that better address issues of trust. Brown said that trust was a major topic at the ECOS meeting on fracking. He thought several models might work, but not enough is known yet to propose one. Wiseman said that New York had probably gone the farthest in bringing together many stakeholders as part of its environmental review process because it has a general regulation that requires broad environmental review for certain activities before approval by the state. She said that Colorado now requires more consultation among agencies in its regulatory process and allows companies to opt for a process with stronger environmental review, which may create more trust. She added that entirely preempting municipal zoning authority, as has occurred in some states, creates a problem for ensuring trust. Rabe commented on a stark difference between Pennsylvania, where legislation has followed party-line votes, and Illinois, where an effort to bring together a variety of stakeholders in advance of legislation led to overwhelming interparty agreement on the legislation that was introduced. No one on the panel knew of any efforts to evaluate stakeholder satisfaction with the decision process in any state.

Substate Federalism and Fracking Policies: Does State Regulatory Authority Trump Local Land Use Autonomy?, Presentation by Charles Davis, Colorado State University

Davis is a professor of political science at Colorado State University with interests in energy and public lands policy making. He began by saying that many factors political scientists normally look at in considering state-level policies, such as diffusion of innovation and policy leadership, do not seem important with fracking, which seems to show idiosyncratic policy development. He said legal relationships between states and local governments are also not the whole story: to understand state-local relationships, one also needs to consider what has been called the policy stream, including changes in public mood, as reflected in public opinion and election cycles. Such changes can be shaped by focusing events and urban-rural differences. He emphasized a point made by other presenters: the paucity of data on these relationships.

Davis used documents, media, and secondary sources to compare Colorado, Pennsylvania, and Texas. These states are among the top six natural gas producers: Texas accounts for nearly 30 percent of all U.S. natural gas production and has been important for a long time.

State versus local control. On the key question of whether state officials should retain regulatory control at the expense of local land use authority, Davis said that most state agencies and most parties in the industry sector say yes. They argue that uniform state regulations allow companies to develop natural gas resources without running into a patchwork of differing policies set by cities and counties. On the countervailing question of whether city and county governments should be allowed to regulate fracking operations under traditional land use authority, Davis said that local governments argue that a "one-size-fits-all" approach across a state is inappropriate for the regulation of natural gas development because of great differences in local social and geological conditions.

Looking at many states, Davis described several strategies that have been used by the industry and other proponents to frame the issue in favor of state control: emphasizing the economic benefits of drilling (jobs, landowner royalties, and severance tax rebates to affected communities); making assurances that fracking is safe (including an industry agreement to emphasize that there have been "no recorded cases of ground water contamination" in over half a century); offering industry and state agency testimony at local government hearings where regulatory actions are being considered by local officials who are relatively uninformed; and encouraging greater collaboration among the state agency, industry, and local officials, including local representation in monitoring and enforcement of environmental regulations (but without independent authority for regulatory action). If a cordial relationship does not materialize, Davis said, proponents then emphasize that the state agency has statutory authority to regulate on a statewide basis. In Colorado, messages from the state attorney general's office have been quite effective, he said, by notifying local officials that legal action will be taken against cities that adopt stricter rules than the state.

Davis explained that key strategies that have been used to preserve local land use authority include emphasizing the importance of home rule and local autonomy; lobbying state agencies for better enforcement of existing rules and increased setback requirements for drilling operators; pointing out the disparity between the number of inspectors and the number of wells (in Colorado, 16 inspectors and over 50,000 wells); adoption of temporary moratoria on fracking operations by local governments while they consider regulatory options; adoption of local policies that exceed or trump state regulatory standards; and at the extreme,

advocating a local or state ballot initiative to ban or establish stronger regulatory policies on fracking.

Davis sees political mood as driven by risk perceptions. National data from the University of Texas indicate that most people want regulation, although there is greater acceptance of fracking among rural than urban residents and greater suspicion of fracking among people who trust EPA compared with people who trust local and state authorities.

State-specific issues. Davis reported that state governors' leadership styles and state government history matter. In Colorado, Governor Hickenlooper believes in task forces and in allowing local governments to appoint inspectors, and he was able to build on the action in the previous state administration to expand representation in the state regulatory commission to include local governmental, public health, and environmental interests. A fracking ban in Longmont was heavily contested because of a concern that other communities might follow suit. In Pennsylvania, Governor Corbett was elected on a strong pro-energy platform that encouraged removal of legal barriers to fracking operations. Davis described Corbett as having "rammed through" legislation, which passed on a party-line vote, that denies drilling impact funds to any local government that adopts policies at odds with state regulations. The law has been challenged in court by the state's Association of Municipalities and environmental groups, and a judicial decision in favor of the plaintiffs has been appealed.

In Texas, Davis continued, the Texas Railroad Commission produces statewide regulations on oil and gas drilling and water quality issues, the Texas Commission on Environmental Quality deals with air quality issues, and local governments have discretion over "conditions of use" such as setbacks. There have not been any Texas state court decisions dealing with the preemption of local authority, said Davis, and there is a lesser degree of organized opposition to shale gas development than in Pennsylvania or Colorado. Some municipalities have used their authority to require "closed loop" systems that store drilling wastes, to adopt major setback requirements, or to ban the sale of city water to oil and gas companies for use in fracking operations during a drought. In New York, which Davis characterized as being on the other end of the spectrum from Texas on state-local relations, local governments are invited to comment on state policies.

Discussant Comments, Sarah Fullenwider, City of Fort Worth, Texas

Fullenwider, the city attorney for Fort Worth, described the experience of Fort Worth with shale gas development and suggested some

lessons for other local governments. Shale gas development started in Fort Worth in 2000, when there was only one relevant state law (which limited drilling within 200 feet of a residence in a populated area). There are now 2,300 wells in the city, 1,000 miles of pipelines, and 41 compressor sites. Because the Texas Railroad Commission does not allow building on plugged or abandoned wells, this growth has implications for future urban development, she said.

The city began by looking at local ordinances across the country to arrive at a regulatory scheme, focusing mainly on setbacks, which can have major effects on the city (a 1,000-foot setback affects 72 acres). Fullenwider said that revisions in city ordinances resulted mainly from industry moving ahead without listening to local residents. She added that municipalities are not in a strong position to influence the industry: they can levy a $2,000-per-day fine for violations, but this is not a large constraint on industry actions. So, she said, municipalities have to convince the industry to cooperate.

She said that when development began, the city didn't look into pipelines and compressor stations. It found that although fracking does not go on for long, compressor stations stay for a long time; are big, ugly, and noisy; lower property values; and have become a large problem. Fort Worth has a permitting system and does not regulate drilling by land use type, except for compressor stations. The city's view on regulation was that it could not ban drilling in the city because it could be sued for "taking" mineral rights which, in Texas, are separate from the property rights of the surface land owners. The argument has also been made, Fullenwider continued, that the city cannot regulate compressor stations because they are part of the pipeline system.

One of the frustrations the city has faced, she said, is that the county has no authority to regulate land uses, including just outside the city limits. Fullenwider identified several regulatory needs, including giving counties enforcement authority; establishing state and federal controls over environmental issues because municipalities are not equipped to do it; improving regulation over the placement of pipelines, which cities in Texas cannot regulate; and considering adopting stringent state rules for the location and use of salt water disposal wells and for the transportation of drilling mud. Drawing on Fort Worth's experience, she identified several lessons for local governments (listed in her slide presentation), most of which relate to educating the local population, particularly in low-income and Hispanic neighborhoods, and educating the industry about urban drilling.

Discussant Comments, William Lowry, Washington University

Lowry, a professor of political science at Washington University with interests in U.S. environmental and energy policy issues, began by noting that policy variation across states is as old as the U.S. government. He said that Davis's presentation is within an old tradition in political science, but addresses two issues that have not been studied much: policy about natural gas, and state-local relations in that context. He sees Davis's paper as a strong early effort to address these issues. However, because the issue is so current, Davis cannot yet offer answers and the theoretical issues are not yet clear. Davis's paper identifies a number of factors that cause variations in states' control of local authorities with respect to the natural gas industry: geological differences, degree of reverence for home rule, the presence of entrepreneurial governors, the involvement of the courts, the level of organized opposition, the economic condition of the state, and the extent of potential problems facing the states. The result, said Lowry, is an idiosyncratic situation, and more explicit theoretical arguments are needed to explain the variations.

Lowry identified several specific arguments implicit in Davis's paper that deserve elaboration. First, his cases do not include states that are not high producers of natural gas: more states need to be studied. Another important issue is partisanship. In the three cases discussed by Davis, Republicans preferred centralized state control and Democrats resisted it, Lowry continued, contrary to the conventional wisdom that says Republicans prefer decentralization. There may, however, be states where Democrats want more state control and Republicans more local control; California might be an example, he suggested. Texas leaves a lot of discretion to localities, but to Lowry it is not clear what the state government would do if a locality wanted to be very restrictive.

Lowry sees another issue raised by Davis's study in the different styles of task forces and collaborative decision making, including which styles promote consensus and which tend toward litigation. The larger literature has not resolved this, he said, and the study of natural gas extraction could help provide answers. A third important issue is the level of opposition in different states. Lowry suggested it might be interesting to differentiate between states on two dimensions: how well organized the opposition to shale gas development is, and the degree of sympathy in the mass media for the technology. Yet another issue he sees is cross-border issues across localities and states. It may be that the more cross-border externalities there are, the greater the pressure for centralized decision making.

A few dimensions may differentiate the states in useful ways, Lowry continued. One is the degree of efficacy of the local opposition, which can be set against the degree of economic dependence of the state on natural

gas production. Lowry's 2 × 2 table of these dimensions suggests to him the following expectations: gas development may most likely be contested where there is strong opposition combined with high economic dependence on gas, strong dependence with weak opposition is likely conducive to state dominance in governance, and weak dependence with strong opposition is probably conducive to the development of local restrictions.

If pressed to make predictions about the future of state-level governance, Lowry suggested another 2 × 2 table representing the state government's attitude to gas development on one dimension and the condition of opposition on the other. He suggested that a "captured" or supportive state government would be risk-acceptant, except when there is an entrenched opposition, in which case, he would expect litigation. A wary state government would be cautious where there is strong opposition and would develop an evolving policy regime when opposition is not entrenched. For him, the most interesting cell in this table is the one in which the state and the opposition are both willing to talk, which is where collaborative policy may develop.

Questions and Discussion

The various participant questions and comments during the subsequent discussion are summarized here under the topics of urban rural differences, implications of mistrust, and communication issues.

Urban-rural differences. A participant suggested that the urban-rural distinction differs by state. For instance, in many Eastern states, rural areas are populated by people who work in urban centers. There may also be differences in the extent to which people in the area are accustomed to oil and gas production. She suggested that much of the opposition comes from people whose livelihoods depend on activities that may be seen as incompatible with oil and gas development. Fullenwider said that the idea of drilling is fairly acceptable in Texas generally, but issues arose with drilling in urban areas. Davis said that comfort levels are affected by the density of wells. In Colorado, the increasing density has been a spur to local opposition, so comfort levels do change. Lowry added that dense development may create more cross-border externalities in urban areas.

Implications of mistrust. A Webcast participant from New York expressed distrust in the industry and in state-level regulations and asked whether, given the industry influence at higher levels, local regulation was preferable to give affected people a chance to control whether fracking happens near them. Fullenwider pointed out that because air and water quality do not stay in a community, a locality that has no regulations imposes risks

on others. Davis added that in Texas, cities have home rule but counties have very little authority.

Another participant asked about collaborative governance and specifically whether panelists saw Colorado Governor Hickenlooper's ideas about collaboration as sincere. Lowry replied he did not know of a good example of a state-level collaborative process, but thought Illinois might qualify. Davis said that events, including local referenda, overtook collaborative efforts in Colorado.

Communication issues. In response to a question about companies and communication, Fullenwider said that companies differ in how they approach drilling in neighborhoods. She thought that those that are successful are very open about what will be happening: They tell people to expect noise and other aspects of the process and ask the community what the company can do to make the process better. The companies that just say they have a right to drill are less successful with the community. She also said that some companies took advantage of less educated populations by getting leases that were highly advantageous to the industry.

The Potential for Managing and Reducing Risk through Nontraditional Regulatory Approaches, Presentation by Sheila Olmstead, University of Texas

Olmstead, an associate professor of public affairs at the Lyndon B. Johnson School of Public Affairs at the University of Texas, presented her work in collaboration with Nathan Richardson at RFF, examining what they call "innovative regulatory approaches." She referred to the RFF survey of experts discussed at the first workshop,[2] and noted that although it found significant consensus about which risks deserve high priority, there was little agreement on whether industry or regulators should take the lead in mitigating risks. Putting aside this question, Olmstead and Richardson's work focused on two approaches to regulation, liability rules and market-based approaches, and their applicability in the shale gas domain. Their work recognizes but does not discuss voluntary approaches engaging both industry and government.

Liability rules. A key question is whether a liability approach has advantages over traditional regulation. According to the classic work of Shavell (1984), liability approaches are advantageous to the extent that four conditions are met: private parties have much higher quality information

[2]See section above titled "Interactions among Risks," which begins with the presentation by Alan Krupnick of RFF.

than regulators, industry actors have sufficient resources to pay liability claims, those who suffer harms have a reasonable chance of bringing and winning lawsuits, and the total costs of the liability approach are lower than those of regulation. In the case of shale gas risks, widespread harms (such as air and water pollution) are hard to address through the liability system, although with other harms, such as from truck accidents or damage to private property or private water wells, liability can fill gaps left by ordinary regulation.

To deal with the significant information gaps confronting some private parties, Olmstead said, a liability regime could include disclosure rules (e.g., for fracking fluid chemicals), establish strict liability rules to remove the need to prove negligence (which increases the need for information), and shift burdens of proof (e.g., in Pennsylvania, a predrill testing law provides that if drillers do not test water before they drill, any ground water contamination is presumed to be a result of nearby drilling). To deal with ability to pay, bonding requirements could be used, though current bonding requirements in many states are insufficient to cover significant damage. Olmstead noted that only eight states have bonding requirements above $50,000 per well. Liability limits, which are being considered in some states, make operators effectively judgment-proof, she said. The largest problem with threats of suits as a risk management approach, Olmstead said, concerns widespread harms. Reducing barriers to class actions strengthens the liability approach, as do information disclosure requirements and providing specialized courts or sufficient numbers of judges and other resources to manage liability suits.

Olmstead briefly discussed administrative regulations, which include prescriptive approaches ("command and control") standards for technologies (e.g., cement requirements for well casings) and for performance (e.g., limits on the pressure level in well casings). The great majority of administrative regulations affecting shale gas development at the federal and state levels are technology standards, even though both theory and presidential executive orders favor performance standards. This suggests that there may be very significant potential for cost-effective changes in regulations, even within the class of prescriptive approaches.

Market-based approaches. These are governance approaches that target aggregate or market-level outcomes, such as the total emissions from shale gas development in a region, and that use flexible mechanisms to achieve the desired outcomes. The approaches include taxes, environmental markets (e.g., cap-and-trade programs), reduction of subsidies, and mandatory information disclosure polices. Olmstead said that these are more cost-effective than command-and-control regulations both in theory and in practice, but there are significant challenges in employing them.

The pollution tax is the classic example, but it is not used in shale gas development regulations. Severance taxes, however, are widely imposed by states. They are used primarily to raise revenue, she continued, but can be used to smooth boom-bust cycles and negative community-level impacts and could, in theory, be used to incorporate some of the negative externalities of gas production. However, the evidence available to Olmstead indicates that severance taxes do not change producers' behavior at current levels or, according to some simulation studies, even at much higher levels. Also, even if they did change behavior, Olmstead said that they might not target some of the most important risks, which do not vary with production levels (e.g., habitat fragmentation from well siting, surface water impacts from impoundments). Impact fees, such as have been established in Pennsylvania, might address some of these "fixed external costs" of well development, and they could be set higher for wells near sensitive habitats. Environmental markets, such as cap-and-trade programs, have not been established for shale gas operations, but some existing programs (e.g., for NO_x and water quality trading) could be adapted for influencing shale gas extraction. Trades within markets for water quantity could also be used where water is scarce. A final type of market-based approach that Olmstead discussed uses information disclosure requirements, such as the requirement for disclosure of fracking fluid contents for operations on federal lands.

In concluding her presentation, Olmstead noted that although there is a lot of thinking ongoing about whether new government regulation is needed and about how stringent it should be, there has been much less thinking about which policy instruments are best for reducing particular risks. Given the large differences in effectiveness, she sees this kind of thinking as especially timely.

Discussant Comments, Kate Konschnik, Harvard Law School

Konschnik, who is policy director of the Environmental Law Program at Harvard Law School, commented from the perspective of her research on states' responses to risks and her past practical experience as an enforcement litigator and an environmental counsel in the U.S. Senate. She summarized Olmstead's presentation as emphasizing two ideas: that regulatory policies need to be matched to the risks, and that incremental changes to existing frameworks should be tried before starting something new. In her experience, legislative bodies are not good at either of those things. To galvanize support, she said, legislators need to identify huge new problems, and when they do, they want to propose large solutions and new programs—usually not well integrated with existing programs.

She said that even though there are many interesting and innovative approaches being discussed, the place to begin is with what is already on the books that may not be enforced, and then identify the remaining gaps, match the innovative strategies to the needs, and make sure there is an off-ramp back to traditional enforcement. She emphasized that having enforcement in the toolkit helps build integrity in the sense that compliant organizations "look silly" if enforcement is weak.

Konschnik proposed four points to keep in mind: (1) It is easier to determine and enforce compliance when there are fewer and larger sources. (2) Agencies are reluctant to enforce against big industries and big companies, even if not "captured" by the industry, because they have limited resources and do not want to use them all in one action—this is not fair, she said, but it is an institutional reality. (3) Environmental rules are historically slow to adapt to circumstances, and therefore often lag behind innovations in industries. (4) Resources are tight and dwindling, in both federal and state agencies. This last point, she added, does open up possibilities for agencies to find volunteer partners.

Konschnik argued that the unconventional oil and gas landscape poses several challenges in relation to these four points. This is a big industry with many large companies, but the pollution sources are small and spread out, she said. There has been much attention to the fracturing phase of the industry, which is new and different, and less to other stages of the process where there sometimes are pre-existing laws that apply but do not work well with an expanded and changing activity. Data on emissions from shale gas operations are very limited, compared, for example, with an energy industry activity like coal-fired power plants. Finally, Konschnik said that regulators' leverage on the industry is weak. The federal government does not have as much leverage to bring parties to the table as in other parts of the energy industry because of exemptions from federal laws.

Nor do consumers have much leverage. To illustrate this last point Konschnik considered chemical disclosure laws, which have been passed in some 20 states for shale gas development, based on the assumption that good information will allow consumers to make rational choices. She said that the assumption fails in this case because gas consumers have no information on which wells their gas comes from. In devising disclosure requirements, governments need to consider which end users could use the information being required: for shale gas, what information would be useful to insurance companies, institutional investors, and so forth? In closing, she reemphasized that any disclosure requirements need to lead back to enforcement.

Questions and Discussion

Monitoring emissions. A participant asked about the feasibility of electronic emission monitoring at well sites, as is done at power plants to help with cap-and-trade schemes and with traditional enforcement. Olmstead replied that this approach may not be realistic with the many thousands of wells that would have to be monitored continuously. Simply permitting all those facilities would be a challenge. Konschnik said electronic monitoring is an alluring prospect, given that the states will never have enough inspectors for all these wells, but she also noted challenges. For example, the Pennsylvania presumption rule about liability from well emissions ends after 12 months, even though emissions from a well may continue for many years. Given the time scale and the number of wells, it will be hard to keep track of emissions patterns within the period of legal liability. It might be possible, she suggested, to lower penalties for wells that install monitors, or to pool liability for surface water contamination, with exemptions for companies that have monitors and can show that they were not responsible for the pollution. Olmstead added that although the technology itself is attractive, many other things would be needed to incorporate it into a governance regime.

Another participant asked if third-party monitoring and verification of compliance could play a role in the shale gas industry. Olmstead mentioned an example of something like this: The Marcellus Shale Coalition in Pennsylvania has brokered an agreement between operators and the state department of environmental protection that the operators would not ship wastewater to a specific set of treatment facilities. This agreement, however, only involved a small group of operators. Konschnik expressed some concerns about the enforceability of that agreement, but did mention other potentially instructive examples. She cited an agreement among U.S. auto manufacturers to create a bounty for mercury switches in scrapped automobiles that auto body shops and scrap metal companies could collect by sending the removed switches to a designated auto manufacturer. U.S. EPA monitored mercury emissions from steel mills, which gave the steel industry an incentive to educate the auto body shops about the program, and auto manufacturers had an interest because they could potentially be held liable for mercury emissions in the air.

Warner North wondered about ways to engage people on a local scale who are not government employees in monitoring dispersed small, local operations. He told a story of monitoring in response to concerns in the Southwest about air exposure to radioactivity, in which Desert Research Institute scientists installed monitoring equipment on weather stations in many small towns and asked local science teachers to collect the measurements and report to the community on the test results. This provided good local information to the community from a trusted source. He won-

dered if this approach could be adapted for monitoring emissions from shale gas operations from many thousands of wells where fracking occurs over short periods of time but local concerns extend over longer periods. Olmstead said that the same spirit is behind entities like FracFocus, which was modeled on the Toxics Release Inventory. The distribution channel for FracFocus is scorecard.org, which has a grassroots feel even though it is a national organization. She expressed skepticism about effectiveness, though, because there is little that local people can do after they have the information. She added that monitoring will be difficult for wells that are on private land.

Konschnik was more hopeful about the prospects for third-party monitoring, despite the access issues. She noted that there are community members who are documenting spills, truck traffic, and other activities of concern, but don't know what to do with the information. She added that U.S. EPA has a small, poorly funded innovation team tasked with building citizen science. To make this approach work, citizens would need to have access to accurate measuring instruments (and she said there is some availability of air monitors to borrow), but there would also have to be actions to take with the information, such as reporting it to a spill-reporting hotline. Konschnik said that this is a nascent area that agencies are trying to develop because of their resource constraints; she sees it as having possibilities. Another participant suggested that a third-party monitoring approach could be applicable after a well is decommissioned by having a local person "adopt" a decommissioned well and continue monitoring it.

Liability as leverage for better practices. A participant wondered whether industry best-practice standards, such as those promulgated by the American Petroleum Institute (API) for shale gas operations, which are not enforceable by any entity, could be combined with the liability system to produce improved governance. Olmstead replied that, even if operators adopt best practices, that may not give other parties legal standing to hold the operators to them. Konschnik said that she thought it will be very difficult to lower barriers to liability action, given that recent political trends are making it difficult to achieve legal standing on a non-economic basis. She thought information about adherence to best practices might be used in some ways, such as to rebut a presumption that the responsible actor is the one nearest to the damage. But to do that, the standards reflecting best practices would have to be harmonized. A potentially important role for the federal government is to harmonize standards and measurement practices, but she thought this is off some distance in the future.

Use of severance tax funds. A participant asked if any states are linking severance taxes to actual environmental costs, rather than setting them as high as possible without losing the industry to other states and then using them for general revenue. Olmstead did not know of any states explicitly using that approach, but she said that some states use the revenues in creative ways. New Mexico is using them to create an endowment that could be used to pay costs after the resource is used. Also, impact fees are assessed over 15 years and could potentially affect behavior. Konschnik said that impact fees are used in many contexts and there may be creative models for using them to affect land management choices. Christopherson commented that impact fees are not based on costs, which have not been calculated, and that they are normally allocated to the municipality where drilling occurs, even if the impacts are elsewhere.

Governing Shale Gas Development in the European Union, Presentation by Elizabeth Bomberg, University of Edinburgh

Bomberg, a senior lecturer in politics and international relations at the School of Social and Political Science of the University of Edinburgh with research interests in comparative environmental politics, began by noting that although Europe is far behind the United States in shale gas development and is different in many ways, it faces many of the same challenges of risk assessment and governance in a fragmented, multilevel system. The European Union (EU), like the United States, she said, varies among jurisdictions both in availability of shale gas deposits and in enthusiasm about developing them. It has an overall constitutional responsibility to ensure a secure energy supply and the smooth functioning of energy markets. It also imposes regulations on chemicals, water quality, etc. Because shale development has been slow, it is putting considerable efforts into developing its regulatory framework. Specifically, the European Union has addressed shale gas development by applying four principles, which Bomberg discussed in detail.

First is the *precautionary principle*, which says that in conditions of uncertainty, decision makers should act to prevent serious or irreversible environmental harm: Uncertainty cannot be an excuse for inaction. This principle, Bomberg noted, is embedded in many EU environmental regulations. The principle, which compels policy makers to gather data and analyze it, has been seized upon by opponents of fracking, who say it implies not proceeding because the risks are too great. It is also used by shale gas proponents, who say that because they are applying this principle, they are proceeding with adequate caution. The proponents' argument has been effective in some reluctant EU states, Bomberg said.

One of the limits of the precautionary principle, she continued, is that it costs time and money. Another is that risks are in part socially constructed, so that scientific assessments may not be conclusive. The principle is applied inconsistently across member states, which slows down development, said Bomberg, because the industry sees an uneven playing field. The key insight, she emphasized, is that this principle needs to be applied with caution, and is not a panacea.

Transparency is the second principle Bomberg discussed. It makes procedures open to the public by requiring registration of lobbyists and a complaint procedure; it also requires substantive transparency (e.g., chemical disclosure). The rationale for this principle, she explained, is partly as a trust-building mechanism but also because it is believed to lead to better policies and stronger accountability. Lack of transparency, Bomberg added, has been a major citizen concern in EU energy policy. She said that the principle's limitations include inconsistent application across countries, the fact that more information is not always better information, and the conflict between transparency and other aims (e.g., closed negotiations may be necessary to achieve some bargains).

Consultation is a principle that calls for interaction with stakeholders. This has been a key priority in the EU, said Bomberg, adding that there has been intensive consultation on shale gas development, including focus groups, stakeholder events, etc., at levels from the continental to the local. The principle's rationale emphasizes information gathering and stakeholder buy-in (called "inclusive governance"). Opponents are engaged from the start in framing the problem, she noted, and there has been much attention to engaging local stakeholders. The limitations of consultation are that it needs to be widespread and balanced (including the range of stakeholders), and that buying in may be perceived as being bought off. Consultation has to happen as policies are being developed, not afterwards, and resources are needed not only for consultation but also for implementing its outcomes. It is tricky to get this right, Bomberg commented, but it is critical.

The fourth principle Bomberg discussed is *environmental sustainability:* The idea that all decision making should consider the transition to a low-carbon economy. This is a much stronger principle in the European Union than in the United States, she said: the main problems with shale gas development are seen to be that it takes resources away from other energy sources and locks in dependence on fossil fuels. Although the European Union has its political reasons for pushing this principle, Bomberg thought that it is also relevant for the United States. She hoped that bringing sustainability into the discussion might help address opposition in states with a strong environmental movement and in highly populated areas. It also opens discussions of ways to use greener technologies

in shale gas development. A limitation that Bomberg finds in sustainability as a principle is that it may be used in contrasting arguments: shale gas proponents employ it to define shale gas as a "bridge" fuel, whereas opponents claim that "sustainable shale development" is an oxymoron. Bomberg suggested that this principle needs to be modified for use in the United States, but embedding the shale gas debate in this frame would lead to a longer-term focus in assessments.

Bomberg concluded by saying that these principles all have strengths and limitations, so should not be applied indiscriminately, but they can be useful in the United States if carefully applied. She emphasized that all the principles are invoked by different actors to advance their interests; that governance requires not only principles, but also their implementation, monitoring, acceptance, and coordination; and that more needs to be learned about best practice in governance from multiple polities.

Governing Shale Gas Development in Canada: The Case of New Brunswick, Presentation by Louis LaPierre, University of Moncton

LaPierre, at the time of the workshop, was professor emeritus at the University of Moncton and head of the New Brunswick Energy Institute. He began by noting that in Canada, each province manages its own energy resources and has its own rules. He indicated, though, that the Canadian provinces will soon be meeting to develop a harmonized approach to shale gas development nationally.

He noted that shale gas is relatively new in New Brunswick, which held a public forum to identify the key concerns in shale gas development. The top concerns expressed at the forum were with government integrity (i.e., widespread mistrust), water contamination, well integrity, and what happens to the fracking chemicals.

Given these concerns and the province's policy decision to move forward with shale gas development, the issue became highly contentious, to the extent that discussions were not leading to progress. LaPierre wrote a report that called for an independent group to develop science-based information to support policy decisions and provide information to both the Minister of Energy and Mines and the public. The provincial government adopted that recommendation and within 12 months established and funded the New Brunswick Energy Institute, with LaPierre as director. He presented information on the structure of the institute.

The institute began working on stakeholder issues that had been raised in several public consultations. A key issue was compensation to people who lost the value of their water wells or who had other losses, by a process managed by an independent ombudsman—a retired chief

justice. Companies were required to put up a bond of CAD$100,000 per well, to be put into a fund administered by the ombudsman, who would make final decisions about compensation. LaPierre said that of the people who opposed shale gas development, 35 percent agreed that if they were assured of compensation, they might agree to development.

Another issue was regulations. LaPierre explained that the government promulgated operation rules, including the registration of fracking chemicals with the government health boards, which allow access to the information by doctors who may need to treat an exposed person.

The institute has a group of scientists, which LaPierre said has brought together 20 fellows from across Canada and the United States to manage research at the institute, and a public roundtable to share information from research. There is also an energy roundtable group, including representatives from a wide spectrum of stakeholders, that shares information, debates issues, and requests additional information from the scientific group. These activities are intended, he said, to enhance understanding, integrate science, and move science into the policy realm by reports to the minister.

LaPierre said that the institute also plans to hold annual conferences focused on various issues. Among those that may be considered are the concerns of many people that shale gas development would lead small villages to "lose their souls" and concerns about the disruptive effects of large numbers of trucks moving through small, quiet villages. In response to concerns about seismic activities, the institute has recently installed a series of near-surface monitors in collaboration with the Canadian geological service. The data from the monitors will be placed on a publicly available website.

Questions and Discussion

Questions About the EU Situation

A participant asked Bomberg how discussions about fossil fuel lock-in and the relation of shale gas to sustainability are playing out in the European Union. She replied that shale gas might be acceptable to many current opponents if used as a transition fuel, but there are doubts about whether this will be the case. Support for renewable energy, which has been very strong in the European Union, has recently begun to diminish. She said that the bridge-fuel argument has not yet depolarized the debate, but she expected that if sustainability becomes central to the discussion, shale gas will be more likely to be developed if it is viewed as a transition fuel than if it is not accepted as such.

Another participant asked if there is common ground among the EU countries that have banned fracking. Bomberg replied that there is no obvious common factor. The member state most strongly opposed is France, which sits on the second largest shale gas deposits in the European Union and has had no difficulty accepting the risks of nuclear power. She sees the economic interests of the nuclear industry at play here. Aesthetic issues also matter in France: French respondents think shale development defaces the landscape. Poland is the most enthusiastic shale gas supporter, she suggested, because of its need to lessen dependence on Russian gas. She said that a factor in some countries may be the pre-existing level of environmental opposition.

A participant asked if the idea has come up in Europe for communities to demand revenue sharing in exchange for allowing shale gas development and to allocate some of that revenue to renewable energy development. This has been proposed in Pennsylvania, noted the participant. Bomberg replied that in Europe, mineral rights belong to states, not to communities, but that some of the many policy innovations in Europe have provided that for each well exploration, money be put into a fund for low-carbon energy initiatives.

Questions About New Brunswick

LaPierre was asked whether the New Brunswick approach might scale to more highly populated places. He said Quebec is planning to use a process like New Brunswick's and that it will be interesting to see what develops. Warner North commented favorably about the compensation system in New Brunswick, which he thought provided for quick and credible compensation to people who might be harmed. He also asked for elaboration about the role of the New Brunswick Institute in shale gas development in the province. LaPierre replied that shale gas development is seen as an important component of economic development in the province, with the possibility of export to outside markets. He said that some of the profits from shale gas would go into a heritage pool to support other industrial development in the province and possibly to convert the transport fleet to natural gas. The province is assessing the gas resource and will conduct a business case study to determine what portions of the gas proceeds will go to the heritage pool, to export, and to the industry. The plan, over a 10-year horizon, is for pilot wells to be drilled under the new regulations and assessed by the institute with regard to production and adherence to the regulations, after which decisions will be made about whether and how to proceed with further development.

A Webcast participant from New Brunswick asked why the institute is going outside the province for expertise, who picked the scientific advi-

sory board, and why there was no public input into who was invited to the roundtables. LaPierre replied that the scientific advisory committee came from New Brunswick, except for one member who had expertise that could not be found in New Brunswick.

COMMENTS ON THE DAY'S DISCUSSIONS

Four of the day's speakers, Sarah Fullenwider, Hannah Wiseman, Elizabeth Bomberg, and Kate Konschnik, were asked to offer their conclusions from the discussions during the first day of Workshop 2.

Fullenwider focused on enforcement. She said that whoever develops regulations has to think about who will enforce them and about their capacity to do so. Without sufficient enforcement personnel, operators will push the envelope. She said that citizens can be valuable in enforcement and pointed to the practice of providing a 24-hour call-in number citizens can use to report spills and other problems. She noted that because of the profit motive, the industry will comply even with strong regulations if the regulations still allow it to profit. In Fullenwider's view, community pressure is even more effective than regulation in influencing operators.

Wiseman said that citizens can assist governments in many ways. She said that disclosing inspection records can be very helpful in getting citizens involved, but that only a few states so far have strong databases with this information. She pointed to the need for better coordination between states and between them and U.S. EPA, but she also noted the difficulty that many agencies prefer to restrict information to protect their reputations. She cited mandatory environmental liability insurance as a promising policy approach, noting that this is different from bonding. When contamination occurs, bonds and support from federal agencies will likely not cover the costs. Mandatory insurance would provide an incentive for insurers to monitor operators and thus improve their performance. In response to a question from a workshop participant, Wiseman noted that willingness to provide insurance is a challenge when there is so little information on the costs. She suggested two complementary approaches to this challenge: provide better scientific information about the risks before requiring insurance and pool the insurance risks, as has been done in the nuclear power industry. Finally, Wiseman cited revenue sharing to reinvest in low-carbon energy options as a way to address the climate implications of shale gas consumption.

Bomberg emphasized the need for coordination across levels of governance, the need for strategies that allow for flexibility (e.g., performance standards), the importance of regional solutions, and the importance of institutionalizing policy learning. She stressed that implementation and

monitoring are critical for the integrity of the governance system and favorably noted some proposals in Europe that would require firms to pay fees to support independent monitoring.

Konschnik spoke about ways the U.S. federal government could help in governance. She identified a role in data collection and data sharing, noting that federal agencies already combine geological and chemical data from multiple sources. They could also harmonize measurement approaches and collect data on best practices in regulation and best practices by companies. She noted that many environmental laws engage the federal government in activities such as setting minimum standards and providing resources, while leaving the implementation and enforcement to the states, and she advocated more cooperation of these kinds between federal and state agencies. An example could be having federal agencies train state environmental employees, she suggested, in contrast to a trend toward industry providing the training, which she found troubling. In response to a question from a participant, she acknowledged that cooperation between federal and state agencies is difficult to achieve, but she said such interaction, especially if it occurs in public, can help build integrity into the governance process.

GOVERNANCE BEYOND GOVERNMENTS

The Potential for Industry Self-Governance

Environmental Self-Governance: Conditions for Industry Effectiveness, Presentation by Aseem Prakash, University of Washington

Prakash is a professor of political science, the Walker Family professor for the College of Arts and Sciences, and director of the Center for Environmental Politics at the University of Washington, with research interests in voluntary environmental programs. His comments summarized general knowledge from several social science disciplines about industry self-governance, drawing heavily on his work with Matthew Potoski (Potoski and Prakash, 2013) on voluntary environmental programs (VEPs). This literature, which includes large numbers of careful case studies but very few field experiments, Prakesh said, addresses three core questions: (1) How can VEPs get started, and who would sponsor them? (2) How can they attract enough companies to join? (3) How can VEPs improve environmental performance at the levels of facilities, companies, and industries?

He defined VEPs as efforts to get companies to go beyond compliance with environmental regulations. VEPs may prescribe systems, standards, or outputs for industrial processes, and they may result from unilateral commitments, bilateral negotiated compacts, or multistakeholder pro-

cesses sponsored by industry associations, nongovernmental organizations (NGOs), governments, or combinations of these.

Prakash sees VEPs as important because firms need economic justifications for environmental stewardship and can no longer find such justification in actions they can take alone, such as by reducing the costs of waste disposal. Firms engage in VEPs because they have the potential to create what Prakash called a market for environmental virtue: They allow firms that are good environmental stewards to identify themselves as such to stakeholders who want to reward them for this. They "brand" firms as good stewards, and this could bring financial benefits. An advantage of VEPs, he continued, is that as collective endeavors, members make a public commitment and face costs for backing out. Also, as more firms join these agreements, there are economies of scale.

There are several valid criticisms of VEPs, noted Prakesh: because they are easy to join, less virtuous firms can easily join and create "greenwashes"; VEPs may preempt stronger regulation; they may "capture" regulators; and they bypass democratic processes. Prakash said that like government regulations, VEPs are only as good as the programs' design: it is important to distinguish good VEPs from bad ones. Two critical design issues are the obligations VEPs impose on members and the monitoring and enforcement of the obligations. The dilemma is that the stricter the regulations, the higher the cost of compliance and the fewer firms that are likely to join. But for VEPs to be effective, they must attract more than just the few best environmental stewards.

Prakash gave several reasons why VEPs emerge. Trade associations sometimes create them to protect the reputation of the industry, NGOs may sponsor them in response to perceived failure of standard regulations, and governments may sponsor them in response to regulatory gridlock. These situations create an interesting politics, said Prakash: firms would like to join programs but don't want to be compelled to do so, with the result that in some industries, such as forestry, there are competing VEPs with different sponsorship.

The decisions of firms to join are, according to Prakash, affected by various external factors, including: pressure from trade associations, some of which require participation as a condition of joining; supply chain pressures (for example, from consumers in one country on suppliers in other countries); community pressures, as when richer neighborhoods place demands on firms that are located there that are not placed on firms locating in poorer neighborhoods; pressure from NGOs; and promises from governments of regulatory and enforcement concessions. Prakash added that the research also indicates that internal factors, such as firms' sizes, environmental compliance history, multinationality, and corporate culture, also affect willingness to join.

Prakash said the question of whether VEPs work is difficult to answer because it requires comparison with what might have been and because it needs to be analyzed at various levels. The research finds that most of the environmental improvements at the facility level are modest and that monitoring and enforcement are critical to efficacy. The research is also identifying new questions, Prakash continued, such as whether programs have spillover effects beyond their members, whether they have a greater impact when public regulation is strong or when it is weak, and whether multiple VEPs in a given sector undermine efficacy.

Prakash concluded with these thoughts: All regulatory systems, voluntary or governmental, share common design characteristics, and all can fail. People should have realistic expectations about VEPs, he said. Replacing public regulation with voluntary regulation is a straw man: the issue is how to add voluntary to governmental regulation, and the major challenge is to improve environmental performance of the small and medium size firms. Prakash noted that regulatory capture has been an issue from the beginning of industrial regulation and will continue to be an issue with both governmental and voluntary regulation.

Assessing the Potential for Self-Regulation in the Shale Gas Industry, Presentation by Jennifer Nash, Harvard University

Nash, executive director of the Mossavar-Rahmani Center for Business and Government at the John F. Kennedy School at Harvard University, has research interests focused on innovation in environmental policy. She considered the potential for effective industry self-regulation in the shale gas and oil sector in particular. She focused on Pennsylvania because there is much activity there, as well as abundant information about the operators in the state and their regulatory compliance. Her premise was that self-regulation should engage the businesses whose activities pose the greatest health and environmental risk: the operators, service companies, gas processors, pipeline companies, purchasers, gas utility companies, and others. Her talk focused only on operators and service companies, even though, as she noted, other actors are also important sources of risk.

In Pennsylvania, Nash continued, the operators are the main point of contact for regulators. There are 75 companies operating more than 9,000 wells, although a few large companies conduct most of the operations. Five companies operate nearly half the wells in the state; 21 companies operate only one or two wells. The five largest operators are quite diverse. Chesapeake, the largest, is the second largest gas exploration company in the United States and focuses mainly on exploration and production. Talisman, the third largest operator, is an international company headquar-

tered in Canada. SWEPI is a subsidiary of Royal Dutch Shell, and EQT is an integrated company that also has pipeline and marketing operations.

Nash said the most common types of regulatory violations involve waste management, pollution prevention, endangering water supplies with waste, erosion control, construction of pits and tanks, and management of cement casings. Environmental performance is uneven, she added: The number of violations and the amount of fines per company is generally related to the size of their operations, but there are some companies with a much poorer environmental record than others by these measures. Nash noted that although operators are legally responsible for the wells, contracted service companies operate behind the scenes and do much of the work that causes the violations. In addition, many new firms are entering the service business. The percentage of this work done by the three largest firms has shrunk from 80 percent to 62 percent in the past decade.

Nash proposed that any effective self-regulatory system would need to address the characteristics of the firms in the sector. Many elements of a self-regulatory system are already in place. There are many trade associations in this space: drillers, small operators, independents, and large operators each have trade associations, and API claims to represent the entire industry. API offers a menu of self-regulatory approaches to its members: product certifications, management system standards, and other purely voluntary approaches. API has some best-practice standards for many phases of industry operations, including forthcoming standards for community engagement and for quality management for service companies.

Nash mentioned two innovations that may be of interest in relation to self-governance in the gas shale sector. One is the Center for Offshore Safety, which was created by API after the Deepwater Horizon accident to promote a "pervasive culture of safety" in the offshore drilling industry, in response to federal requirements that offshore drillers implement safety and environmental management systems and that there be third-party auditing and certification. Another interesting example comes from the American Chemical Council's Responsible Care program, which requires that members adopt a Responsible Care management system that must be independently audited and verified. The American Chemical Council is now rolling out this program to its supply chain.

Nash concluded by identifying several factors that either inhibit or enable self-regulation. Inhibiting factors include the diverse set of players, ranging from small "mom and pop" companies to large, global businesses; the difficulty of identifying best-practice leaders; the importance of service companies in undertaking environmentally risky activities, mostly behind the scenes; the fact that existing self-regulatory programs are purely voluntary; and the absence of a collective identity among firms

or a galvanizing event to shape such an identity. Enabling factors include the increasing attention to the risks among the public, lawmakers, and firms; the concern by some companies that their reputations might be tarnished by bad actors; the fact that the industry has taken some first steps; and new emerging models that emphasize third-party auditing and certification. These new models, Nash said, are worth a closer look.

Questions and Discussion

The discussion raised various issues about the potential effectiveness of industry self-governance approaches. Participants' questions and comments are summarized here under the headings of relationships of self-governance to government regulation, governance of service companies, issues with multiple VEPs, variations among states, interactions with communities, and the "greening" of fracturing fluids.

Relationships of self-governance to government regulation. In response to a participant's question, Nash said that industry has at times gotten in front of regulation and then had its standards incorporated into regulation. She noted that many API best-practice standards have been incorporated into regulation in the past, and this might happen again with the shale gas industry, with API standards being incorporated into state codes. Prakash added that this happens in many countries that have weak regulatory capacity and take cues from multinational corporations. He said that with shale gas, the United States could be viewed as a failed state, with a patchwork of governance for a very important industry. One school of thought, he said, is that the real added value of voluntary programs appears when the state is weak. But for effective voluntary regulation, there must be demand for it, in the form of stakeholders that hold firms accountable and demand evidence of environmental stewardship. He sensed a lot of public mistrust and unease, which has not yet been channeled into concrete demands for specific activities.

Jan Mares of RFF identified a limitation to self-governance and an implication for the government role. He cited a report from RFF, *Prudent Development,* which concluded that because the oil and gas industry is highly sensitive to antitrust actions claiming that companies in the industry have conspired to restrict competition, it resists self-enforcement against bad actors. As a consequence, the National Petroleum Council, which is mainly an industry body, has recommended that federal and state regulators be given adequate funding and personnel for effective oversight, possibly using a fee-based funding mechanism dedicated to the purpose.

Governance of service companies. One participant reported from personal experience in Pennsylvania that many operators subcontract risky operations to service providers who simply go bankrupt when costly damages appear. He suggested that this environment creates obvious challenges for effective industry self-governance. Another participant also questioned the ability of voluntary approaches among operators to influence service companies, citing an example of an operator who wanted to be responsible but claimed it cannot impose its standards on service companies because they move quickly from one operating company to another, and each operator has different standards. Nash responded that the bankruptcy issue poses a worrisome challenge and that the issue of the relations between operators and service providers is critical. She was encouraged by efforts of the Center for Offshore Safety to provide model contracts with service companies that include provisions such as third-party monitoring. Prakash added that it is possible for operators to band together and establish standards for their subcontractors. He said this approach has been taken successfully by clothing companies in establishing labor standards for the suppliers of their products in multiple countries. A participant from the industry distinguished between companies that look at environmental protection from a liability standpoint and those that see it as a responsibility. He said his company falls in the latter group and has established programs in which it requires its service companies to participate. He advocated that states establish criteria for approving service companies and that companies only hire approved service providers.

A participant asked whether, to address the problem of poorly capitalized companies doing the dangerous work, there are models in which voluntary actors draft and use codes, for example, to determine insurance rates or to decide whether to offer loans. Prakash replied that in essence, this question is asking whether enforcement is possible by parties other than the government. He said that this is an exciting area for development, given the highly decentralized nature of shale gas operations. A key to this approach is auditing, with third-party auditing being the gold standard. Prakash proposed that community-based monitoring is needed, that it is in the interest of the responsible firms, and that it deserves to be pursued.

Issues with multiple VEPs. A participant asked if there are any signs of competition among would-be certifiers in the shale gas industry, as there has been in the forest products industry. Nash said the shale gas industry is ripe for that kind of competition, which could ratchet up performance. For example, the new CSSD standards may compete with API's purely voluntary approach. Prakash noted that it is unclear whether a multiplic-

ity of standards tends to promote a race to the top or to the bottom. In his view, without a galvanizing event in this sector, the premium attached to a stringent standard is not yet visible. He also noted the problem of information overload, which makes it hard for stakeholders to tell which labels are credible. Eventually, he suggested, there may be a shake-up in which firms with different needs for social license will gravitate to different sources of labeling.

Variations among states. A participant asked if variation exists among states in relation to self-regulation; for example, is there more self-regulation when state government is weak or when public opposition is strong? Nash replied that an active and engaged community will be the impetus for both governmental regulation and self-regulation and that the threat of government regulation is an impetus for self-regulation. These pressures seem to be arising in some states, she said, and when it happens in enough states, national trade associations may take on the challenge. Prakash suggested that if the Marcellus compact gets acceptance, it will be copied and modified elsewhere.

Interactions with communities. In response to a question, Nash said that communication with local communities is a major problem and that the petroleum industry does not yet have a code of practice for this. Prakash reiterated that although there is widespread concern about risks, there are not yet clear community demands. He said that although public acceptance is a long-term issue for the viability of the industry both in the United States and globally, at this stage, the industry lacks the incentive to communicate well. He thinks that eventually, the industry will realize that its viability depends on better communication.

The "greening" of fracturing fluids. A participant asked if there has been any voluntary emphasis on greening of fracturing fluids. Nash said that at this point, attention is mainly on disclosure of the fluids; the hope presumably is that disclosure would lead to interest in greening the fluids. She noted that the FracFocus database has some serious deficiencies and needs strengthening—for example, the service companies are not even mentioned, and they are the largest users of fracking fluids.

THE POTENTIAL FOR RISK GOVERNANCE THROUGH ORGANIZATIONAL SAFETY CULTURE

Presentation by Nancy Leveson, Massachusetts Institute of Technology

Leveson is a professor of aeronautics and astronautics at the Massachusetts Institute of Technology who studies accidents from a system theory perspective. She introduced herself as a safety engineering professional with management expertise who has worked with the oil and gas industry for decades. She said that safety cultures exist in whole industries and in individual firms, that they involve underlying value systems, and that they do not change easily with organizational changes. She noted three industries with strong safety cultures: commercial aircraft, nuclear power, and the nuclear Navy, saying that these safety cultures developed for different reasons. In commercial air travel, William Boeing recognized in the 1950s that there would be no airline industry if people did not trust its safety, so he began promoting safety culture within the industry. The nuclear power industry was stymied by its inability to get private insurance against catastrophic losses. In response, the federal government, under the Price-Anderson Act, agreed to provide this insurance but only if the industry agreed to be regulated. The nuclear Navy established its outstanding safety program, Subsafe, after the 1963 *U.S.S. Thresher* accident. Before then, there had been submarine accidents every 2-3 years; since that time, no U.S. submarine has been lost.[3]

Leveson said that one cannot count on industries to learn from accidents. The usual pattern is that if an accident happens to another company, it is blamed on that company's failings; if it happens within a leader's own company, it is typically blamed on a very low-ranking person and then forgotten. Sometimes, though, there is learning from accidents. After the Three Mile Island accident, said Leveson, the nuclear power industry created the Institute for Nuclear Power Operations (INPO), an excellent organization that puts a lot of peer pressure and oversight on operating companies. Her second example of change in safety culture was the Colonial Pipeline company, which had had so many accidents that the U.S. Justice Department was threatening to jail the chief executive officer (CEO). The company then replaced the CEO. Although it took a long time to change, Leveson continued, the company eventually developed, and got all employees to buy into, a philosophy that held that all injuries and accidents are preventable; safety will not be compromised for any other business objective; leaders are accountable for the safety of employees,

[3]The Subsafe Program is discussed in Leveson's book, *Engineering a Safer World*, which can be downloaded at no cost from the MIT Press Website at http://mitpress.mit.edu/books/engineering-safer-world [July 2014].

contractors, and the public; and preventing accidents is good business. Leveson emphasized that these principles need to be backed up by action to be trusted and to become effective.

Next, Leveson identified three types of flawed safety culture. The most common, and the one that she sees as most prevalent in the oil and gas industry, is a culture of denial. In this culture, leaders only want to hear good news; leaders dismiss credible risk assessments and warnings without appropriate investigation; and accidents are treated as inevitable and the price of productivity. In a compliance culture, companies focus on compliance with government regulations and produce strong arguments about how safe a company's operations are. A paperwork culture issues a lot of analyses that have no effect on operations.

Leveson has found it incredible that many companies in the oil and gas industry claim that they have outstanding safety records. Examples of the culture of denial in this industry include claims that "our accident rates are going down," apparently based on whatever statistics give the best answer; the idea that "this is just a dangerous business"; and the idea that "everyone has safety violations." Leveson noted that a plane flying at 30,000 feet and a submarine in the deep ocean with a nuclear reactor on board present more dangerous environments than those in the oil industry, and yet they have better safety records.

In response to a request by the workshop organizers for ideas on ways to develop a strong safety culture in this industry, Leveson pointed first to strong leadership as key to safety culture, saying that an organization's tone and values are set at the top. She cited as a blatant, negative example the response of NASA's leadership to the 2003 space shuttle *Columbia* disaster: The head of the shuttle program made strong, immediate public statements about the importance of safety but then, the next day, sent an e-mail to staff making it clear that the priority on safety was second to the priority of reaching the program's goals. Leveson said that an organization's staff understands its true priorities by seeing how decisions are made, how resources are distributed, and whether high-ranking officials are made responsible for safety.

As a positive example, Leveson cited Alcoa, where, when Paul O'Neill took over as CEO, he told his investors that "I intend to go for zero injuries." The initial response, in the words of one stockbroker who heard the message, was to say that "the board put a crazy hippie in charge and he's going to kill the company." He advised his clients to sell quickly, Leveson continued. But the company's profits hit a record high in the first year after O'Neill's speech and continued to increase throughout his tenure, while Alcoa became one of the safest companies in the world. Leveson said that O'Neill understood that increasing safety increases productivity, rather than the objectives being in conflict. She described safety as a

"keystone habit" that ripples through an organization. To illustrate, she pointed out that O'Neill gave his subordinates his home phone number and invited them to call him at home if they saw a safety problem. After a while, she said, O'Neill began also getting calls at home with other suggestions for improving the company.

Another critical point, Leveson said, is that blame is the enemy of safety: when you start blaming people, they stop talking and hide small problems. She said that blame is all over the oil and gas industry, but noted that on the other hand, peer pressure from safe companies on others can be very effective. The drilling moratorium after the Deepwater Horizon disaster resulted in the good players in the industry putting pressure on BP and supporting a new center for offshore oil safety. Leveson argued that an industry's customers often have more power than government. As an example, she said that although the U.S. Food and Drug Administration will not do anything about radiation overdoses from medical devices, the physicians who buy the machines and who care about their patients have been starting to write standards and impose them on producers. Leveson described API's standards as ineffective and suggested that if there is a way to involve the customers safety could be improved by changing the incentive structure for the industry.

As a final example of customer power, Leveson described the efforts of Costco to create an alliance of retailers, food growers, and farm workers to reduce food contamination. Previously, farm workers, who are paid piecemeal, could expect to lose pay if they reported contamination, so they rarely did so. The alliance teaches workers how to spot signs of food contamination and trains them in good practices, while offering better pay and working conditions. The program effectively places auditors (the trained workers) all along the production chain. Leveson added that unexpected benefits have been better worker retention and improved worker morale, effects that have been seen in other industries as well. Although Costco is paying more for its produce, she said, it is betting that consumers will pay a bit more to protect their children from illness.

Discussant Comments, Jennifer Howard-Grenville, University of Oregon

Howard-Grenville is an associate professor in the Department of Management and the Center for Sustainable Business Practices at the University of Oregon. She has studied the integration of a design-for-environment approach in the semiconductor industry and is examining "sustainability culture" in the oil sands industry in Canada. Commenting from the perspective of organizational theory, she said that there is very limited research on how organizational culture responds to environmental issues, but much more is known about safety culture. The two

are different in that safety issues can be put in personal terms, whereas sustainability issues are harder to express that way. Still, work on safety culture can offer insights. That research emphasizes that communication is important, but has to be reinforced by modeling, incentives, and training, as well as by efforts to ensure that individuals and groups feel able to act on company commitments.

She noted that the organizational culture literature emphasizes shared values, which can either advance or impede achieving environmental goals. In the oil sands industry, one company was known for being innovative and taking risks, so introducing routines there was very difficult. Howard-Grenville also identified day-to-day patterns and practices as "cultural resources," which may reside at group, organizational, and industry levels, somewhat independently of values. She said they can move from one company to another, but they need to become part of the organizational culture to be effective.

Discussant Comments, Donald Winter, University of Michigan

Winter, whose career has included service as president of TRW Systems and as secretary of the Navy, offered comments based on his experience in the defense and aerospace industries, where he had responsibility for dealing with safety issues, and on his experience reviewing the causes of the Deepwater Horizon oil spill. Like Leveson, he cited the Navy's Subsafe Program as a good example of a properly designed safety management system and distinguished it from what is employed in the oil and gas industry. He noted that Subsafe is not a general-purpose safety program. It focuses only on whether submarines can submerge and surface safely—the two events of greatest concern. It does not address other occupational safety issues on naval bases or in submarines. However, from a focus on those two specific concerns arise a number of important standards for equipment and for personnel. Individuals are told regularly of their responsibilities and of what happens when mistakes are made, with vivid representations of the lost lives. The Navy has a very strong concept of responsibility and accountability, holding commanding officers accountable for whatever happens on the ship as soon as they accept command, and it can remove commanders after serious incidents occur, even if this happens soon after they accept command. Knowing that they are accountable in this way leads commanders to focus on safety from the moment they take charge. Winter believes that the focus on personnel is key to success and more important than any focus on technology.

Winter contrasted practices in the Navy with what he sees in the oil and gas industry. Despite budgetary pressures, the Navy has so far been able to make the case that it should not build submarines the way China

or Russia does, at lower cost but with less attention to safety. The oil and gas industry, by contrast, organizes itself for efficient use of capital and for management of liability. These priorities appear to Winter to inhibit appropriate accountability among employees. For example, if a company were to hold managers accountable when accidents happened, it would amount to an admission of error and could expose the company to liability.

Winter said that the industry has to recognize that developing a strong safety culture is critical. Safety always involves tradeoffs, particularly between safety and productivity, but in the oil and gas industry, CEOs often put strong priority on reducing costs over other objectives. Winter emphasized that written rules are never adequate for making these tradeoffs because technology is changing too fast. What is needed is a culture that supports making the proper tradeoffs. He also said that the industry needs to fix the personnel accountability issue and that regulators need a mechanism for rewarding contractors who employ a proper safety culture. He drew a contrast with the U.S. Department of Defense, where he said decisions are based on best value, which is not the same as lowest cost.

Questions and Discussion

Possibilities for improving safety culture. Hannah Wiseman suggested some possibilities and asked the panelists to comment. One would be to establish an oil and gas industry equivalent of INPO, which engages industry, government, and nonprofit groups. Leveson responded that an INPO-like entity would be a good idea, but that government could not be involved because companies would not reveal information. Winter added that INPO is populated by Navy veterans who have long experience in nuclear power operations.

Another possibility suggested by Wiseman was to establish safety departments that were separate from operations and that would be responsible for giving bad news when appropriate. The presenters were not enthusiastic about this approach. Winter does not favor separate departments because the safety issues cannot be divided that way. He noted that BP has a separate safety department, but that department has no authority over operations. He said that to improve safety, the safety culture has to be embedded in every unit. He suggested as a model the Navy's concept of independent technical authority, which establishes that an individual responsible for operations cannot deviate from set standards without approval by someone outside the group who has been given the authority to attend to the safety issues and is not subject to cost pressures.

A third suggestion from Wiseman, to have government agencies or nonprofits publicly reward good performance, did not receive further comment from the speakers.

During this discussion, Winter suggested that competition is a barrier to cooperation in reducing risks at the industry level. He pointed out that unlike the oil and gas industry, the nuclear power industry is not competitive. With competition, he said, proprietary considerations are very strong and there is a tendency not to share information. Leveson said that competitiveness is not an insurmountable barrier, noting that even though the commercial aviation industry is highly competitive, it has figured out ways to share anonymized information and has experienced great gain from doing so in the promotion of safety.

Measuring safety culture. In response to a question about how safety culture can be measured, Leveson said that the industry confuses occupational safety, personal safety, and system safety, treating personal safety as a matter of individual responsibility, but treating system safety very differently. She said that most measurements of safety culture look only at occupational safety. Winter added that occupational safety is easy to measure, but statistics for major events like the Deepwater Horizon accident are few, and such events are not directly comparable. He said that culture is what people do when no one tells them what to do: to assess safety culture, one needs to understand how decisions are made and tradeoffs are adjudicated between productivity and safety. Howard-Grenville agreed that safety outcomes can be measured, but the field is less good at measuring aspects of safety culture that produce those outcomes.

Relationships between safety culture and sustainability culture. In response to a participant question, Leveson said that safety and sustainability involve different value systems and do not intrinsically go hand in hand; however, her concept of system safety includes environmental considerations. Winter said that to promote safety, one needs great attention to detail, and that sensitivity to detail can help achieve all kinds of safety objectives because people learn to think through their decisions.

PUBLIC AND STAKEHOLDER PARTICIPATION FOR MANAGING AND REDUCING RISKS

Presentation by D. Warner North, NorthWorks, Inc.

North, the president and principal scientist at the consulting firm, NorthWorks, Inc., applies decision analysis to issues facing private companies and government agencies in the areas of energy and environmen-

tal protection. He began by summarizing material from previous NRC reports (National Research Council, 1983, 1996, 2008) regarding how to ensure good use of science in areas of uncertainty and controversy and particularly how to involve interested and affected parties, for whom he used the shorthand term "stakeholders." The 1983 NRC report, *Risk Assessment in the Federal Government,* known as the "Red Book," said that risk assessment needed to be tailored to the needs of risk managers and that this requires a two-way dialogue. He said that the leadership of EPA misunderstood the need for conceptual separation between risk assessment and risk management as a call for organizational separation. EPA thus decided it was appropriate to begin with risk assessment and then pass the risk characterization over to risk managers for action, as opposed to having a dialogue about the nature of the problem and how best to characterize the risks.

North said that stakeholder involvement has been interpreted by many as having stakeholders speak, write comments, etc., but that the key is two-way communication, including respectful listening. The standard environmental impact statement and notice-and-comment rulemaking procedures use linear processes in which documents are prepared and comments are then solicited. It is not surprising, he continued, that with controversial issues, the notice-and-comment process is widely perceived as breaking down. The 1996 NRC report, *Understanding Risk: Informing Decisions in a Democratic Society*, described a process of two-way communication that moves back and forth many times between analysis (information gathering, interpretation, etc.) and deliberation in order to improve both analytic activities and decisions. That report emphasized five key needs: (1) get the science right (which was a major concern in the 1983 report as well); (2) get the right science (which means framing the problem in a way that speaks to the concerns of the interested and affected parties; (3) get the right participation; (4) get the participation right; and (5) develop an accurate, balanced, and informative synthesis.

Public Participation in Environmental Assessment and Decision Making (National Research Council, 2008) examined available knowledge about getting the right participation and getting the participation right in the hope initially of agreeing on specifics of what is and is not good practice. The committee ultimately concluded that this is more of an art form. Its report defined quality, legitimacy, and capacity as three objectives of public participation. It concluded that when done well, public participation can advance all these objectives, but the report also noted that participatory practices have sometimes made matters worse. To summarize a very detailed report, said North, what is needed is leadership and respectful listening, including listening to the outliers and dissenters, and ensuring that what they contribute is effectively evaluated. Analysis and delibera-

tion are both critically needed, he emphasized, and the people who are expert in one may not be expert in the other.

North then turned to the issue of combining analysis and deliberation in the area of shale gas development, which he saw as particularly important for problem formulation. He noted that analysis can occur at many levels. At the global level, shale gas is abundant in many places. Considering concerns with greenhouse gas emissions, North said it should be recognized that in China, shale gas could replace the one coal-fired power plant being opened each week, but methane releases remain a concern. At the national level, concerns about sustainability, energy policy, and the economic benefits of lower-priced energy all favor shale gas development, but when gas is cheaper, renewable energy systems are less competitive. Deciding whether shale gas can be a short-term "bridge" raises complex national policy questions.

The regional level, North continued, was the main focus of this workshop. In his view, the presentations and discussions suggest several areas where an analytic-deliberative process has substantial potential: (1) planning and managing community impacts; (2) making decisions about disclosure of the chemicals in fracking fluids and the possible replacement of toxic chemicals with saline water; (3) addressing the disposition of produced water, regional water allocation, and related regional planning issues such as land use; (4) seeking improved safety culture for reducing air and water emissions and developing monitoring processes and sanctions for poor performance; (5) developing ways to listen to workers and other people who might report deviations from best practices; (6) developing best practices for checking well integrity, probably including independent inspections by local authorities; and (7) agreeing on methods to determine whether there have been leaks of contaminants or methane and on ways to assess damages.

North concluded that shale gas development is a complex policy issue akin to nuclear power and waste management, nanotechnology, and others. For such issues, the analytic-deliberative process shows a lot of promise, he said, adding that getting it right will be tricky, but worth trying.

Discussant Comments, Patrick Field, Consensus Building Institute, Boston, Massachusetts

Field is managing director of the Consensus Building Institute and associate director of the MIT-Harvard Public Disputes Program. His work as a facilitator seeks to help stakeholders reach agreement on natural resource, land use, water, and air issues. He began by noting several conclusions that came from a recent forum he facilitated for the Union of Concerned Scientists, which paralleled the conclusions of the 2008 NRC

report. The forum concluded that there are important questions both about whether shale gas should be developed and if so, about how it should happen. It found that community engagement is essential for both information sharing and decision making, but doing this is hard. Among the forum's insights were that there are difficult questions about how much control should be local; property rights regimes are fundamental, and these are subsurface rights; the audiences are numerous and complex; declining trust in institutions is a challenge; and information, power, and control are asymmetric.

Field identified four areas of opportunity: information disclosure, joint fact finding, improving the industry's capacity for stakeholder engagement, and community engagement.

Information disclosure. He said that "secrets" promote fear and suspicion and that disclosure is trusted more if information is produced jointly. Still, disclosure is not a panacea. In the case of fracturing fluids, according to Field, disclosure will be trusted either if done by a government or if it can be audited by a third party. He said that FracFocus does not yet have all the characteristics it needs to be trusted and noted that some academic institutions have gotten in trouble about the sources of financial support for their research.

Joint fact finding. To date, Field said, institutions do not meet the three-pronged test that good information must be salient to decisions, credible, and legitimate. He said that there are some good examples in other energy sectors: in wind development, the Health Effects Institute (for air quality information), and several research foundations that inform water utilities. He suggested that some of these might provide models to adapt.

Improving the industry's capacity for stakeholder engagement. Field considers this important because governments lack the needed resources. He added that engagement needs to be linked to companies' operational decision making and that effective companies need to be rewarded for their work.

Community engagement. Field said that although this is important, it is also difficult, partly because of value differences and lack of trust. Field cited the 2008 NRC report as suggesting some ways forward. He said that community advisory groups and liaisons have lessons on which to draw, as well as complaint and grievance mechanisms, charters that identify shared principles, and some international initiatives that provide third-party verification and that companies may want to join.

Field said that assessing the quality of community engagement is difficult, but there have been some efforts to jointly build things like community scorecards for participation. He concluded that stakeholder engagement is necessary but can only be sufficient when it has a path to action. He added that thought needs to be given to ways that local winners from shale gas development can compensate losers, to improve the societal balance.

Questions and Discussion

Engagement of opponents of development. In response to a participant's question about this, North said that decision making is often difficult in a democratic society. Although he was pessimistic that everyone will come to an agreement on shale gas development, he expressed hope that the communities represented at this workshop can inform the decision makers of all the viewpoints, including those of people who are in vigorous disagreement. Other participants agreed that polarization of views is a major challenge. Field suggested that the goal of getting everyone to agree sets a very high bar, but the goal can be defined as engaging everybody and building as much agreement as possible, recognizing that some people may cause problems later. Reaching this limited goal can be very constructive. Small added that there are issues on which agreement can be sought other than whether to develop, such as about where and when to develop, and what background data should be collected before proceeding.

Public participation at the local level. A participant asked what can be done to engage local government proactively with local citizens in considering the risks of shale gas. North hoped that this workshop might enable participants to carry lessons back to their communities. Field said that local governments present major opportunities but are challenged by a shortage of resources: they regularly set aside money for litigation but not for collaboration. In addition, it is not always clear who the convener should be within local government, and there can be problems when local officials are labeled as being for or against development.

Simona Perry, Case Consulting Services, offered several comments from her experience working with communities in Pennsylvania. She proposed that procedural transparency—including making discussions among decision-making organizations public—is a more fundamental need than disclosure of chemicals. She said that problem formulation needs to happen at the local level, with experts in facilitation engaged, as well as experts on shale gas issues. She also argued for a culture of collaboration and listening, including transparency about discussions

and decisions by government agencies, landowners, and the industry and finding spaces for people to listen to each other. North commented that the frustration of people in Perry's position is in getting the backing of decision makers and the resources to organize the participation at the level and for the length of time required. He said that greater recognition is needed of the need for these community-level discussions.

Representing the concerns of future generations. In response to a question about how these concerns can be incorporated in a public participation process, North said that the present generation needs to take seriously its responsibility to future generations, including in formal risk analyses. He cited a recent paper by Kenneth Arrow and colleagues (2013), which argued that discount rates should be set lower because of uncertainty about effects a century or more in the future. North sees this as great progress in economics beyond analyses of 20 years ago, which seemed to cut off consideration about any consequences beyond 2100. Field added that some people in public participation processes act as proxies for future generations. He also noted that there are generational tradeoffs in energy choices—both developing gas and not developing it have consequences for future generations—and participatory processes need to get people to consider those tradeoffs.

Compensating losers. A Webcast participant from New York State asked if there are good examples of compensating the losers in shale gas development. Field said that there have been efforts to develop community benefit packages in wind energy development and to find better ways to manage the benefit flows. He added that there are unavoidable value questions as well, such as about the effects of industrial development on rural landscapes, which cannot be addressed by financial compensation. LaPierre said that in New Brunswick, a new structure has been proposed to divide royalties from shale gas development between the provincial government, the local government (for example, for road construction and repairs), and the landowners.

Disclosure issues. A participant suggested that the need for disclosure extends much farther than fracking fluids: people who sign leases and live in communities need to know a lot more about the consequences of their choices than they hear from landsmen who sometimes suggest that the industry will be in and out of an area very quickly. North agreed that disclosure should include all the materials that might spill or leak, as well as the other effects of industrial development, which can be very visible and audible.

Measuring success. A participant noted the difficulty of measuring the success of public participation. North said that when public participation is successful, it is rarely well documented because the problem is no longer salient and because the people responsible have moved on to other activities.

Promising approaches. North expressed hope that the Internet may enable new mechanisms for public participation, suggesting that its use might decrease the resource requirements, such as travel funds. He also strongly advocated the need to institutionalize independent, outside analyses by highly qualified people who can comment on the complex issues that shale gas development will continue to entail. This was done with the establishment of the Nuclear Waste Technical Review Board in 1989, he said, and it is needed for other emerging technologies, including shale gas. He noted that decision makers will need to be convinced to charter such an organization and to commit the significant resources that will be needed to support it.

REGIONAL EXPERIMENTS IN SHALE GAS RISK GOVERNANCE

The Center for Sustainable Shale Development, Pittsburgh, Pennsylvania

Andrew Place, the interim director of CSSD, described it as an experimental collaboration of industry, philanthropy, and environmental NGOs seeking what he called a social license to operate. The project seeks to develop high standards for operation that go well above the minimum standards set by regulations. The people who created CSSD wanted to do something about the polarization around shale gas development and agreed that development needs to be done responsibly. He identified the organizations involved and noted for transparency purposes that he is employed by one of them, EQT Corporation, a natural gas producer in the region. The center is hiring a permanent executive director. Place said that to seek balance, the Board of Directors has four seats designated for industry, four for environmental NGOs, and four for other members he describes as "nonaligned." Balance is also kept by the implicit threat that one side or the other could withdraw from the organization.

As the conceptual foundations for CSSD, Place cited documents by the Secretary of Energy Advisory Board, Shale Gas Production Subcommittee (2011), the National Petroleum Council (2011), and the International Energy Agency (2012), all of which call for engagement, collaboration, transparency, and measurement. He said that CSSD has looked

to many past efforts for insights on best practices, rather than trying to invent ideas from whole cloth.

The center focuses geographically on the Appalachian Basin, reflecting the uniqueness of shale gas regions. Place went on to say that standards need to address unique issues down to the level of well sites. CSSD did not try to engage all the operators at first but rather to engage those who might agree on some useful standards. Over time, trust has increased among members of the initial small group.

The center has been developing standards initially in two areas: emissions into air (including greenhouse gases) and risks to ground and surface water. It is developing standards in these areas before moving to other issues, in order to make some progress quickly, although the other areas are also important. CSSD focuses on certification and verification. Place said that certification will require audits both in offices and on sites by an independent third-party auditor. He briefly described the center's ground water protection standards, which include standards for casing and cement; a minimum of 90 percent recycling of wastewater; and a number of other standards for well pad design, operations, monitoring, disclosure of fluids used, and spill response and public notification plans. Standards for air emissions include removal of hydrocarbons from flowback and produced water before storage; at least 98 percent destruction efficiency of flaring; and emission standards for engines for drilling rigs, pumps, compressors, trucks, and condensate tanks.

Place concluded that the essential attributes of CSSD are its collaborative nature, the obligation it imposes on members, and its adaptive nature, including the intention to expand over time to cover the whole life cycle of risks. More details on CSSD's activities can be found at its Website: www.sustainableshale.org.

Maryland's Comprehensive Gas Development Plan

Christine Conn and Brigid Kenney, respectively of the Maryland Department of Natural Resources and Maryland Department of the Environment, described that state's proposed Comprehensive Gas Development Plan (CGDP). Conn described the CGDP as focusing on issues of the location of wells and the cumulative impact at landscape scale of placing multiple wells, with the aim of addressing these issues before permits for wells are issued. Maryland has only about one percent of the Marcellus shale play within its borders, all of which is in very rural areas of western Maryland where outdoor recreation and tourism are the main industries. The governor issued an executive order in 2011 that established an advisory commission with representation from a broad range of interested groups and required a series of studies of short- and long-term effects of

gas extraction, to provide information to policy makers who will decide whether to proceed with development.

One study commissioned for the CGDP has produced a best practices report with recommendations for all aspects of exploration and production. The report evaluated the scientific literature and practices in other states; in response to that report and to consultation with the advisory commission, the Maryland agencies drafted a report that contains the CGDP, which is currently out for public review and comment. The study said that the CGDP, which is modeled on efforts in Colorado and by the U.S. Bureau of Land Management, was the most important best practice. The goal of the CGDP is to allow efficient exploitation of the resource while minimizing impact on local communities, ecosystems, and natural resources.

A second commissioned study reviewed comprehensive development plans in other places and explained the need for comprehensive, landscape-level planning and the potential for win-win outcomes. To illustrate the need for landscape-level planning, Conn showed a map from Pennsylvania that indicated what a landscape could look like if permitting proceeded well by well. The first report to the CGDP group called for pads with multiple wells as a way to limit impacts on the surface.

Conn said that the Maryland plan calls for the CGDP to be approved before any wells are allowed; for the plan to cover development over at least 5 years; for it to address locations of pads, pipelines, and roads; and for drilling to meet location restrictions and setbacks prescribed in the plan and to avoid sensitive areas and minimize cumulative effects. Under the CGDP, an application to drill a well can be processed if the location is consistent with the approved CGDP and if plans for the well demonstrate that proposed activities will meet or exceed regulatory standards. The CGDP is also addressing colocation of wells to leverage existing land uses and minimize overall impact and is considering open disturbed lands as the first choice for well location. The state is developing the CGDP as a "toolbox" with geographical data that companies can use to develop plans and that the public can also use.

It is the job of Kenney's agency is to implement the CGDP. She said that developers would have to submit plans, which would be reviewed by the Department of the Environment to ensure compliance with state and local requirements and to consider opportunities for coordinated regulatory review and alternatives to the proposal. Applicants are then required to initiate a public participation process, she said. They must identify stakeholders, including the company, NGOs, land owners, and citizens, to participate in a process that is open, is ideally professionally facilitated, and considers alternatives to the submitted plan. This process is intended to happen within a 60-day period, after which applicants can

change their plans. The Department of Natural Resources evaluates the process and the plan, and the Department of the Environment decides on approval. Applications must still be processed for individual operations within the plan. The plans are approved for 10 years but are subject to change under a streamlined approval process.

Kenney identified some concerns that have been raised about the Maryland approach. One is whether it should apply to both exploratory and production wells. The Department of the Environment believes it should apply to both because exploratory wells often become production wells. Another issue is whether the approval criteria (e.g., avoiding adverse impacts to the environment) can be adequately defined. Other concerns described by Kenney include whether the plan adequately controls cumulative impacts and whether it is both strict enough to be effective and flexible enough to be practical without forced pooling, which Maryland does not allow. Companies have expressed concern about additional costs they may bear in acquiring lease and right-of-way agreements. Kenney said that the report that contains the CGDP, when finalized, will have a roadmap for implementing the CGDP if shale gas development is approved. She said that more information on the activities in Maryland can be found at the Department of the Environment Website, available at http://www.mde.state.md.us [July 2014].

Discussant Comments, Kate Sinding, Natural Resources Defense Council

Sinding is a senior attorney and deputy director of the Natural Resources Defense Council's New York Urban Program, working on issues including efforts to ensure strong environmental regulation of natural gas drilling. She began by emphasizing that efforts like CSSD can only be a supplement to government regulation. She believes the first priority is to identify and fill gaps in government regulation before putting substantial resources into voluntary processes. Although many states are making advances in regulating this industry, she stressed that there are still many gaps to fill and resources may still be inadequate. She said it would be refreshing to see more of the kind of coming together of different groups that has occurred with CSSD, but her organization has found that almost all the shale gas companies have been unwilling to make commitments to uniform and tougher regulations. All of the best practices identified by CSSD could in fact be put into regulations that would apply to all companies, and Sinding proposed that doing this would benefit the better actors by leveling the playing field. She emphasized that the success of voluntary efforts depends on recruiting more of the industry actors to adopt these best practices.

Sinding said that the long-term success of voluntary efforts depends on there being a downside to not playing by the rules. Ultimate consumers cannot bring consequences to bear on production companies because the purchasers are mainly utility companies and large industries; unless these proximate customers make a commitment to purchase only from certified companies, there is no downside. She was also skeptical about the possibility that a "galvanizing event" would produce significant change in industry operations. She believes that most of the recommendations of the commission after the Deepwater Horizon oil spill have not been implemented. She also pointed out that catastrophic events in this industry are much smaller than in oil drilling or the airline industry, so may not have much of a galvanizing effect.

Sinding endorsed the specific best practices CSSD has recommended and commented favorably on the emphasis in the Maryland CGDP process on cumulative impact and on planning for ancillary uses and infrastructure, neither of which has been taken up by New York. She spoke against forced pooling, saying that respecting property rights should be treated as a cost of doing business, that such costs are the price of doing business in a democratic society, and that to limit the impacts, perhaps developers should not be allowed to develop as much shale. Whether the Maryland plan is strict enough will have to be assessed as the plan moves forward. Her final comment stressed the need to consider the largest-scale cumulative impacts: the effects on climate of being locked into fossil fuels. She said this conversation is not happening at all, and it may need to happen at the federal level.

Discussant Comments, Mark Boling, Southwestern Energy, Houston, Texas

Boling is an attorney and president of V+ Development Solutions at Southwestern Energy. He commented that although the gas industry has been highly innovative below the ground, that is, in extracting gas, it has not been very innovative above the ground. He said that regional plans have been a long time coming. Few oil and gas companies have land use planning as part of their organizations, but he believes that adding this innovation can help optimize locations of infrastructure, truck traffic, and road damage. He also noted the need to address social issues, such as those that have arisen in communities in the Bakken shale play, and he said that this kind of planning should precede development. He added that plans need to be seen as tools and not as redundant regulation, both to reduce strain on governments' budgets and to reduce resistance from industry.

Boling was skeptical about plans that lock in too many decisions, noting the need for enough flexibility to make some changes without

restarting approval processes, in order to reflect legitimate reasons industry does not want to be committed to a fixed development process years in advance. Some of these reasons have to do with what is learned about a location from initial drilling experiences; others relate to costs to industry if, for example, a plan commits a company to siting a compressor station at a particular spot before it has negotiated with the landowner. Boling noted that coordinating development plans among operators is unconventional, though worthwhile; it will require innovations in the ways industry operates and does contracting, which currently happens one well at a time.

Boling thought that the plans that were presented do not pay enough attention to water supply, transport, and disposal, all of which relate to truck traffic and other issues and which require planning on a regional or watershed basis. He agreed with Sinding that CSSD has to be considered as a supplement to government regulation, not a substitute, though he offered a different reason: the public views the industry as already underregulated. Finally, he supported the idea of regular meetings between industry and local officials so the latter understand what is happening. In his view, local moratoriums arise from distrust of governments at higher levels. He concluded by saying that going beyond what is required makes the difference between the industry being tolerated and being accepted.

Questions and Discussion

The potential for national-level standards. A participant asked Place which standards or best practices might transfer well across regions and suggested that closed-loop systems, flaring regulations, and practices for impounding reused flowback are probably appropriate nationally. Place said that a lot of CSSD's standards probably do make sense nationally, but that was not the focus. He thought a flaring standard would look different in less-populated areas or in areas where air quality is already in nonattainment of regulatory standards. CSSD sought to tackle issues only at a local level, even if they are also national or global issues.

Relationships between voluntary agreements and regulations. The presentations stimulated much further discussion of this issue. Conn said that although her agency supports voluntary programs like CSSD that set a high bar, it would still like to see standards codified in regulations. Kenney added that if voluntary standards were evaluated by state regulators and found to meet or exceed state requirements, companies that complied with them could automatically be qualified as meeting state regulations. Place supported this kind of approach. He said voluntary and regulatory practices could inform and cross-pollinate each other and

added that one value of voluntary approaches is that they can lead regulation by drawing on the technical skills possessed by the industry. He said CSSD is not arguing against regulatory approaches. Sinding agreed with the other comments and said that she did not mean to downplay the value of voluntary approaches. She recognized that voluntary approaches might be more nimble than regulations but wanted to emphasize the significant gaps that remain in the regulatory regime and that need to be fixed. Mitchell Small commented that voluntary standards might eventually be turned into regulations, perhaps through negotiated rulemaking, following paths that have been followed in other areas of environmental regulation.

Discussion of the CSSD effort. In response to a question about who will be doing audits for CSSD and about their accessibility, Place said CSSD is putting together an accreditation protocol for auditors and will make that information public. He said that accessibility of audits is a work in progress, but CSSD is committed to public accessibility. Unresolved issues relate to disclosure of sensitive business information. He added that in his experience, fuller disclosure can greatly reduce some disputes between industry and NGOs about air and water quality issues.

Another participant asked how CSSD was able to get buy-in from industry groups, given the possibility that companies might refuse to participate in voluntary programs if the standards are too high. Place said that this was tackled in part by focusing narrowly and by being clear that the center was developing standards, not regulations. Concerns remain, he said, about whether these standards will lead to tighter regulation—which raises the question of "threading the needle" between the priorities of different groups and finding some middle ground. Place was gratified that there were some shared values and that compromises could be made on technical details within those values.

Place was also asked about whether certification was to be done for wells or operators, the willingness of major companies to become certified, and whether he sees other performance standards in the future, such as perhaps for community engagement. Place said that certification was for operators and applied to all their unconventional operations in the Appalachian Basin. All four firms in the program are committed and want to go forward with the first round of certification. He sees terrestrial impacts, safety, and community impacts as among the top priority areas for future action.

Discussion of the Maryland Plan. A participant asked the Maryland presenters if they thought total-harm standards could be established for potentially affected systems, such as water levels in streams, on a land-

scape basis. Kenney replied that the Maryland standards try to incorporate total harm where possible, but noted that that there are unresolved issues about whether certain issues will be settled in the CGDP or later. Conn added that information related to total harm, such as about areas that are sensitive to water withdrawals, is being included in the Maryland toolbox.

FINAL SESSION: PERSPECTIVES ON GOVERNANCE CHALLENGES

Five workshop participants—Mark Boling, Bernard Goldstein, Kate Sinding, Susan Christopherson, and Barry Rabe—were invited to offer their thoughts at the end of the workshop.

Mark Boling, Southwestern Energy

Boling framed his comments in terms of what should be regulated, by whom, and how. He said we have a good idea of what needs to be regulated: water and air emissions, water use and reuse, surface impacts, and so forth. Who should regulate is a more difficult question. Decisions about this ought to be driven by what is most effective and efficient for regulating the risks, he said, and that depends on five things: the scale of impacts, whether the risks are the same from state to state, whether the proposed solutions are the same, whether the regulatory authority needs special knowledge about local conditions in order to regulate effectively, and whether there are legal preemption issues. An additional consideration is who is in the best position to keep pace with changes in technology and the need for continuous improvement in regulation. For fracking fluid disclosure, Boling favors a national standard, although he noted that some in the industry would disagree. He expects that this issue will follow the history of chemical regulation, in which diverse state standards eventually gave way to federal ones.

On the "how" question, Boling said that the public will insist on traditional types of regulation, and he agreed that those are needed. He noted that social impacts need closer attention but seem to be the last issues getting it. Following his idea that industry needs to innovate above ground as well as underground, he called for a fresh look at the risk mitigation strategies the industry has in place. He said that "smart regulation" is needed, which he defined as risk management that strikes the proper balance among economic, social, and environmental impacts. Smart regulation requires collaboration to identify the risks, assess them, propose mitigation strategies, test the strategies, and translate the results into regulatory language to establish a level playing field for all in the

industry. He said this is normal practice in private contracting. What makes it so difficult when the public is the other contracting party is that both actual risk and perceived risk are important, and the latter drives public opinion and public policy. If there is a tremendous information gap between actual and perceived risk, he cautioned, we cannot get to smart regulation. To close that gap requires collaboration and risk communication. Boling concluded by saying that only with smart regulation can public trust be won.

Bernard Goldstein, University of Pittsburgh Schools of the Health Sciences

Goldstein commented first on issues of trust and transparency. In a recent study he did of people who believe shale gas development is harming their health, he found that many complain about noise, smells, and the like, but most of them also raise trust issues: "they lie to us," "no one answers the phone," etc.

Goldstein focused most of his comments on the difficulty of governance in this particular industry. One challenge is that failures are not recognized immediately, as they are with an oil spill or a disaster in the nuclear power industry. Many public concerns about shale gas are with more insidious effects such as cancer. Moreover, the effects may be mediated by so many different media that monitoring of the causes is very difficult.

Another challenge is the diversity of the actors, along with the problem of subcontracting, which make it hard to determine who is responsible for any effects. The RFF study listed 264 risk items, and these need to be considered in relation to the very large number of actors who might be responsible. Goldstein said that FracTracker data on 36 companies showed great differences among companies in the rate of infractions, suggesting a safety culture issue. If safety culture is a major problem, it would also show up in differences in worker health, but the structure of the industry, with contractors, subcontractors, and temporary workers, makes it hard to track worker health in this way. He said more transparency is needed on these data and on the chemicals themselves. Even though Colorado and Pennsylvania require disclosure of fracking chemicals, there is an exemption in Pennsylvania for flowback fluids that come up from underground but that the companies did not put there. Goldstein saw this as a reversion to the "bad old early days" of environmental regulation. Not telling people what is in the flowback fluids makes the industry look as if it is not transparent, he said.

Finally, Goldstein made the point that the companies with strong safety cultures are the ones that allow monitoring. He suggested that

because of this, available data likely give an unrepresentative and probably overly favorable view of the whole industry. This possibility, said Goldstein, implies that an effective monitoring approach will have to include a fair amount of government oversight.

Kate Sinding, Natural Resources Defense Council

Sinding focused on two themes in her comments. One was the avoidance of fossil fuel lock-in, which she sees as a major governance issue that requires serious critical thinking that is not happening at either federal or state levels. In her view, the prospect that shale gas will displace or delay the transition to a lower-carbon economy implies that more should be done than just strengthen policies on energy efficiency and renewables; governmental intervention will be required at the federal and international levels. She found the idea of putting severance dollars into energy efficiency and renewable energy exciting but said it probably will not be enough. The bottom line, as she saw it, is that if all the shale gas is developed and all the money for infrastructure is sunk into this development, the risk is being locked into a medium- or long-term energy future dominated by fossil fuels, which is not an acceptable outcome. Even though natural gas is a relatively clean-burning fuel, and even if the methane emissions are captured, Sinding argued, the worst predicted climate impacts will not be avoided. Thus, she disagreed with the view that natural gas is a panacea for our climate problems, as some in the federal government propose. She urged the workshop participants to take this up as one of the major governance issues that must be addressed.

Sinding's second theme was that respect toward American democratic principles should be a cost of doing business for this industry as it is for other industries, including the clean energy industry. She emphasized that this industry is not regulated like other industries: it has special exemptions from some federal environmental laws; it uses eminent domain; and it benefits from legal primacy of minerals estate over surface estate, forced pooling, lack of public access to information, and lack of procedural transparency. All these special treatments put oil and gas development on a different playing field from other industries. Many of them are of long standing and unlikely to change soon, she continued, but the degree of local governmental authority is still in flux. There are takings issues that will make it impossible for local governments in some places to "just say no." But in New York, where development has not started yet, Sinding said that local government has been able to get ahead before takings issues arise. She argued that municipalities should have broad authority to regulate where and, within reason, how shale gas development should take place. The desire to get it out of the ground should not

trump deeply held democratic principles, she emphasized, adding that, as Charles Davis's presentation had suggested, these principles can coexist with the desire for development. Sinding concluded by saying that many of the comments responding to the elicitation presented at the start of the workshop reflect a lot of chafing by stakeholders about these issues.

Susan Christopherson, Cornell University

Christopherson said that these two workshops represent what, in her view, the National Academy of Sciences was created for: to address complex public policy issues in order to improve the quality and legitimacy of decision making. She sees them as providing a very important national service. She added that the workshops have changed her perspective somewhat. They demonstrated the necessity of looking systematically at the entire development cycle, from sourcing of sand to transport of products across the country and for export. These considerations imply that impacts occur distant from where extraction is occurring and that this is a national issue, involving up to 33 states directly and other states indirectly through transport of materials, water extraction and disposal, and migration of human populations.

She said that a systematic perspective also requires analyzing the development process over time, including attention to boom-bust cycles and long-term and cumulative impacts on everything from long-term land use patterns in Fort Worth to long-term public health impacts. She said that the workshop led her to recognize that shale gas requires concern at the federal as well as at the state and local levels and to accept a need for federal regulation: "We need a policy that is more systematic than 'all of the above'."

Barry Rabe, University of Michigan

Rabe offered three observations. The first concerns the distribution of costs and benefits. He found it interesting that some of the most promising ideas about using revenues from shale gas development to compensate affected communities have come from New Brunswick in Canada and from Europe but not from U.S. states. He said that four U.S. states will get at least a billion dollars in shale gas revenues this year, but in all cases, the money will be used for general state purposes. Transfer of funds for compensation deserves much more attention, and in Rabe's view, has been a missed opportunity both for improving the human condition and for building political consensus.

Rabe also raised questions about the federal government role, especially because of cross-border concerns among states. He asked rhetori-

cally if we are prepared to take off the table the issue of whether the current roles of states and the federal government are adequate to the need, just because it has been almost impossible to approve any federal environmental legislation over the past 25 years. He suggested that more thinking is needed about what serious regional governance would look like.

Finally, Rabe expressed gratitude to the organizers of the workshop for the great rigor and integrity of this process. He said that all the social sciences are needed to address the issues of shale gas development, and that they need to "bring their A game." By contrast, many of the available publications are not peer-reviewed, he said, and some authors have failed to reveal conflicts of interest, thereby tarnishing the reputations of social science research fields that are much needed going forward. He concluded by saying that the National Academy of Sciences needs to do more along these lines and that doing so will help the nation move forward in constructive ways.

FINAL COMMENTS AND DISCUSSION

The workshop chair, Mitchell Small, opened the floor to brief final comments, summarized below, from any of the participants present.

Standards and liability. A participant asked Boling to comment on the possibility that setting standards and best practices in the industry creates a standard for liability litigation and therefore acts as a kind of governance. Boling said that it would be little solace to a landowner to have the right to sue if a company trashes his property. In his view, if these standards raise the bar, so be it. He would rather have damages be prevented than resolved by lawsuits.

Research ethics. Konschnik commented on the need for standards of research ethics in an area like this, in which the industry supports much of the research. She called for ways to quantify the quality of the research. She mentioned a practice at the University of California, San Diego, of pooling research funds from various sources so that investigators do not know where their particular funds came from. Rabe said there are lessons from public health and medical sciences, where there are extensive provisions for disclosure and data archiving that can be adapted in this field. He also suggested an explicit effort to develop a code of ethics. He said that severance taxes and other such sources could fund pools for research funding and establish rules for funding the research. Christopherson pointed out that foundations and other nonindustry funders often have policy agendas today, so they should be included in discussions about research ethics. She said that nonindustry funders may not realize that

they may get better policies by asking neutral research questions, rather than those driven by their policy agendas.

Next steps. Goldstein strongly expressed his opinion that, notwithstanding the value of these two workshops and a previous one organized by the Institute of Medicine, a broadly framed consensus study should have been undertaken to make recommendations on shale gas development. The chair concluded the workshop by noting that the workshops' proceedings will remain publicly available, there will be a published workshop summary, and the organizing committee will be preparing a special issue of the journal *Environmental Science & Technology* that will include papers developed from these workshops. In his view, the workshop has succeeded in meeting its goals of clarifying the mechanisms and state of knowledge about risk governance for shale gas, identifying potential enhancements to risk governance, and providing workshop participants with new insights and contacts to help them better understand and consider risk governance options. He expressed the hope that the participants and the workshop products being developed will help disseminate what had been learned and also that an appropriate sponsoring entity will support a consensus study that will allow this progress to be further advanced and disseminated.

RISKS AND RISK MANAGEMENT IN SHALE GAS DEVELOPMENT: THEMES, CHALLENGES, AND OPPORTUNITIES

In this section, the rapporteur organizes the presentations and discussions at this workshop under several broad themes. One recurring theme was that shale gas development is proceeding faster than systems to manage the associated risks. Several participants at the workshop identified challenges for risk management that they believed were important. Several also suggested what they saw as potentially valuable opportunities to explore and consider in future discussions about the development of shale gas resources.

Issues of trust. Distrust of both industry and government appears to be a major challenge for risk management. Many public concerns (for example, in responses to the elicitation prior to Workshop 1, as well as in multiple comments from presenters and participants) relate to what are seen as greedy corporations, inadequate regulations, inadequate information, unfair legal regimes and distribution of risks, and inadequate public participation. A number of workshop presenters and participants identified strategies for addressing the trust issue. Many involve imple-

menting principles of precaution, transparency, and consultation, such as have been promulgated in the European Union (see the presentation in Workshop 2 by Elizabeth Bomberg). Opportunities that were mentioned include enhanced information disclosure, monitoring, and risk analysis via independent third-party institutions; joint fact-finding activities; implementing credible methods for compensating losers in the development process; and organizing public consultations in advance of legislative and executive decisions that provide for meaningful two-way communication, as advocated in previous National Research Council (1996, 2008) studies.

Risk management by governments. Several presenters and participants identified fragmentation of authority as a major challenge for risk management by governments. In the United States, the shale gas industry is exempted from several federal laws that govern other industries, a situation that delegates risk management responsibilities largely to state and local governments. Finding an appropriate and effective balance and distribution of governance responsibilities thus becomes a major challenge. Some workshop participants suggested that the best opportunities for negotiating an effective balance are in states where shale gas development has not yet begun. Others noted that the regional nature of many of the risks (e.g., water and air quality) presents a major challenge for both local and state governments, whose jurisdictions are determined by political boundaries. As several presentations and discussions illustrate, some emerging regional planning and governance units and regional centers are attempting to address these challenges and may provide useful models and lessons.

Another major challenge that was repeatedly noted is that many of the state and local agencies with risk management responsibilities are viewed as lacking capacity in the form of adequate staffing, funds, and expertise to anticipate, monitor, and regulate the risks. This challenge, several participants said, is compounded by increasing pressures on governmental budgets, the widely dispersed nature of shale gas extraction, and limited data on emissions and risks. A number of workshop participants identified several possibilities for addressing the capacity issue at the state and local levels, including using permitting fees or severance taxes to fund and train state and local risk management staff and finding volunteer partners (e.g., local citizens who could monitor emissions if provided with reliable equipment). It was also suggested several times that the federal government could help by collecting available scientific knowledge in an easily accessible form; training state environmental employees; harmonizing measurement approaches; and providing databases to enable uniform data collection across states about gas development activities, emissions,

impacts, policies, and lessons learned. Another point expressed by multiple participants is that heterogeneity among states in both resources and governmental structures nevertheless presents serious challenges for risk management.

Many of the participants suggested ways governments might act to support nonregulatory risk governance. Governments might, for example, require insurance for operators in the industry or support a liability regime for risk management by such methods as establishing disclosure rules, strict liability rules, higher bonding requirements, and shifted burdens of proof. Another suggestion was that market-based risk management approaches involving severance taxes and impact fees and markets based on air and water quality measurements are worthy of more careful consideration.

Risk management by nongovernmental entities. Particularly during the second workshop, several participants discussed the potential to improve risk management through voluntary self-regulation by the industry and stronger cultures of environmental protection in individual companies, both of which, according to several presenters, could in principle supplement governmental action or even proceed in advance of it. A number of participants believed such voluntary approaches have been effective in some industries. In the shale gas industry, according to several participants familiar with the industry, increasing public attention to the risks has raised concern in some companies that their reputations might be tarnished by bad actors, providing an incentive for action by groups of companies independent of government regulation. However, a number of participants noted that effective voluntary action may be difficult because of the prevalence in the industry of very small companies and the roles of service companies that are not highly visible but undertake many of the risky activities. Also, these efforts may face problems of trust. Developing strong organizational environmental protection cultures remains a challenge: several participants with relevant expertise offered reasons they thought it unlikely that these would become widespread in shale gas development firms in the near term.

Other challenges and opportunities. Integrating the management efforts of public, private, and nonprofit entities emerged in numerous comments as both a practical necessity and a major challenge. One view expressed at the workshops is that global risks of shale gas development, primarily related to locked-in dependence on fossil fuels and consequent climate change, pose management challenges that rise above national governments and require serious attention. Several participants identified a major opportunity for addressing many of the above challenges by using

impact fees, severance taxes, or other taxes on shale gas development to manage the risks by funding monitoring and regulation, compensating affected parties for harm, and investing in low-carbon energy options. Until now, these taxes have been mainly used for general revenue and, according to some workshop participants, have not been set at the appropriate levels or distributed in the appropriate ways to address the risk management challenges.

Research needs. Many of the participants identified research needs that they believe could make important contributions to public understanding, risk management policies, and public trust. Some of the efforts suggested would build on expanded third-party monitoring and uniform data collection to improve understanding of the effects of shale gas development and the various kinds of risk it poses. Other efforts would examine the effectiveness of various data and information systems, risk management policies, and methods of collaborative decision making on managing the risks and earning trust.

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