Addressing the Societal Costs of Unconventional Oil and Gas Exploration and Production: A Framework for Evaluating Short-Term, Future, and Cumulative Risks and Uncertainties of Hydrofracking

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This article proposes a framework for addressing societal costs—psychological, social, community, and human health risks and uncertainties—associated with natural gas extraction and production from tight shale, tight sand, or coalbed methane formations that use hydraulic fracturing processes. The US Environmental Protection Agency's 2011–14 study of hydraulic fracturing and the risks posed to drinking-water resources is used as a case study of how such a framework could be applied. This report also discusses some of the current regulatory and institutional barriers that make incorporation of societal costs into science-based and proactive decisions regarding unconventional oil and gas exploration and production in the United States more difficult and recommends some general steps for getting past those barriers.

Environmental Practice 14:352–365 (2012)

The high-volume, slickwater hydraulic fracturing process used in unconventional [United States (US) Energy Information Administration, 2012] oil and gas exploration and production (E&P) involves injecting large volumes of water and a combination of various chemicals, including friction reducers, biocides, acids, and proppants (such as silica sand or ceramics), under very high pressure to fracture the target geological formation and release the methane gas (Andrews et al., 2009). The exact proportion of chemicals used varies at each gas well and is considered proprietary business information or a trade secret by gas companies (US Department of Labor, 2012). It is this step in the E&P of unconventional oil and gas, commonly known as *hydrofracking* or *fracking*, that has garnered the most attention from the national public and news media and prompted numerous scientific studies and regulatory investigations, including a study by the US Environmental Protection Agency (US EPA) in 2011–14 to assess the impact of hydraulic fracturing on drinking-water resources across the US (Bamberger and Oswald, 2012; Entrekin et al., 2011; Groat and Grimshaw, 2012; Hammer, VanBriesen, and Levine, 2012; McKenzie et al., 2012; Urbina, 2011; US EPA, 2011; Warner et al., 2012).

In the EPA's plan to study hydraulic fracturing, scientists and regulators plan to study the entire water life cycle as it relates to the use of hydraulic fracturing for extraction of oil and gas resources from shale. Although this study is not labeled as a risk assessment, the agency describes it as providing information that "can then be used to assess the potential risks to drinking-water resources from hydraulic fracturing activities" (US EPA, 2011, p. 3). The EPA considers *risk* to be "the chance of harmful effects to human health or to ecological systems resulting from exposure to an environmental stressor" where a stressor is "any physical, chemical, or biological entity that can induce an adverse response" (US EPA, 2012a). To characterize the nature and magnitude of human health and ecological risk from chemical contaminants and other stressors, the EPA conducts environmental risk assessments. Therefore, in this report, the EPA study is considered critical to conducting a risk assessment at some point in the future.

While the EPA focuses on hydraulic fracturing and its impact on water resources, preliminary social science and public health research conducted in regions with unconventional oil and gas development have found that the largest con-

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 doi:10.1017/S1466046612000336

cerns of residents living in these communities are only indirectly related or may be not at all related to the hydrofracking process. In fact, preliminary research looking at perceptions of community leaders in Pennsylvania's Marcellus Shale region shows that, at the local community level in areas where hydrofracking is being conducted, this one step in the multistage process of unconventional oil and gas development is not even cited as an immediate or short-term impact (Brasier et al., 2011). Instead, in community-based studies in Pennsylvania and Colorado, local residents feel they are most impacted by the increased traffic, road destruction, dust and air pollution, noise, chemical and wastewater spills and accidents, erosion and sedimentation, changes in the quality of their private water wells, unusual and new health problems, large-scale and rapid landscape change, overall feelings of uncertainty, an increased number of new people ("strangers," "outsiders," or "foreigners") in their community, and a sense that their communities are changing almost overnight from rural to industrial and more urban (Perry, 2012; Witter et al. 2010). One of the first responses from public health experts and the research community to these local community concerns about unconventional oil and gas development has been a call for more complete and full disclosure of all chemicals and chemical mixtures used by the industry, including chemicals used in well site preparation, well drilling, hydrofracking, well production, gas processing, and transport. Such chemical information is necessary in order to design more appropriate epidemiological and toxicology studies (Goldstein, Kriesky, and Pavliakova, 2012). There have also been calls for more studies on the psychological and social stress factors in oil and gas–impacted communities and for wider use of community health impact assessments to gauge public perceptions of risk and to document emerging health problems (Institute of Medicine, 2012).

Incorporating community health impact assessments into environmental risk assessments and studies like the EPA's on hydraulic fracturing may be one way to account for the costs to society and local community concerns (Agency for Toxic Substances and Disease Registry and US EPA, 2009). Community health impact assessments may also help prevent a mismatch between local community concerns and questions and national concerns and scientific questions that may lead to false conclusions about the risks posed by unconventional oil and gas development at the local level, as well as to local community mistrust of the entire research or risk-assessment process. However, it is important to recognize that broader and long-term community concerns, unless explicitly incorporated into such health or environmental assessments up front, may not get addressed. These broader concerns include questions about the cumulative nature of pollution—that is, regarding how legacies of pollution interact with new sources of contamination from unconventional oil and gas development and affect local environmental and human health outcomes. They also include questions about the short-term and long-term psychological and social impacts on local residents, including how the fears and uncertainties regarding pollution can create psychological and social stress leading to poorer health outcomes. Therefore, it is essential that scientists, public health experts, regulators, and policy makers recognize that conducting environmental assessments that focus solely on the impact of hydrofracking and that minimize or ignore the local or regional societal implications of the various processes involved in unconventional oil and gas E&P may lead to faulty decision making and make it more difficult to accurately identify local hazards and manage risks and uncertainties in the future.

This article proposes a framework for the comprehensive identification and incorporation of societal costs, including psychological, social, community, and health factors, associated with unconventional oil and gas E&P. Through critical analysis of the EPA's 2011–14 study to assess the impacts of hydraulic fracturing on drinking water, this article explores how such a framework could greatly improve the quality and usefulness of risk assessments in addressing societal concerns. It is also a general call for a shift in how the EPA and other government agencies conduct their impact studies and risk assessments of complex human-ecological problems. To enable this shift, nongovernment scientists and public health practitioners from various disciplines must become more engaged in scoping, planning, analyzing, and managing environmental risks related to unconventional oil and gas development.

Current Risk Assessments and Scientific Studies on Hydrofracking

One of the most comprehensive regional assessments of the risks of unconventional oil and gas development in the US was conducted by the New York State Department of Environmental Conservation in 2011 (NYS DEC, 2011, pp. 9–13). Through a public scoping process, extended public comment periods, and input from engineers, geologists, and other scientists and specialists within the NYS DEC's natural resources and environmental quality programs, the "Revised Draft Supplemental Generic Environmental Impact Statement" identified nine main categories of potential significant adverse impacts associated with hydraulic fracturing operations in the region's Marcellus Shale formation: (1) water resources impacts; (2) impacts on ecosystems and wildlife; (3) impacts on air resources; (4) greenhouse-gas emission impacts; (5) socioeconomic impacts; (6) visual, noise, and community-character impacts; (7) transportation impacts; (8) impacts of naturally occurring radioactive materials (NORMs) and technologically enhanced naturally occurring radioactive materials (TENORMs) in produced water, pipes, and other equipment; and (9) seismicity (NYS Department of Environmental Conservation, 2011, pp. 9–19). Many of these same impacts have been identified in reports by other municipal agencies and academic researchers (Beauduy, 2009; Entrekin et al., 2011; NYC Department of Environmental Protection, 2009; Osborn et al., 2011; Soeder and Kappel, 2009). However, noticeably lacking from the otherwise comprehensive analysis by the NYS is an assessment of human health impacts over the short-term or long-term, whether through environmental (including noise and visual) pathways or associated with changes in socioeconomic status and other community characteristics.

With regard to the link between environmental pathways and human health and hydrofracking wastewater disposal, preliminary results of ongoing collaborative research between the Pittsburgh Water and Sewer Authority and the University of Pittsburgh School of Engineering and at Carnegie Mellon University has shown that produced waters from Marcellus Shale development are a major contributor of total dissolved solids (TDS), including and most significantly bromides, to the Allegheny and Monongahela Rivers (States et al., 2011; Wilson and VanBriesen, 2011). These bromides can interact with the chemical treatment systems in public drinking-water systems, increasing the risk of brominated trihalomethanes (THMs) entering public water supplies. THMs are known to cause an elevated risk of birth abnormalities and certain types of cancer in people exposed over long periods (Dodds et al., 1999; World Health Organization, 2004).

Other research and regulatory investigations have set out to better understand the groundwater and surface-water risks resulting from drilling and hydrofracking activities (Legere, 2011; Ohio Department of Natural Resources, 2008; Osborn et al., 2011). In one case, the Pennsylvania Department of Environmental Protection (2010) found that bubbles along the western bank of the Susquehanna River in Bradford County, Pennsylvania, were thermogenic methane gas, the result of a Marcellus Shale gas well being drilled 2 miles away. However, this is not an isolated event. In another methane migration case in Susquehanna County, Pennsylvania, in Dimock Township, the US EPA and the Agency for Toxic Substances Disease Registry (ATSDR, a federal public health agency of the US Department of Health and Human Services and the Centers for Disease Control) became directly involved in conducting comprehensive analysis of existing water test results at 18 private homes and new water testing of chemicals at 68 private homes whose drinking-water wells were suspected to have high levels of methane caused by gas drilling in 2008 and possibly containing metals and other chemicals of public health concern (ATSDR, 2011a). Although it is a clear safety concern in confined spaces, what risks, if any, methane migration poses to drinking-water quality and human health remains an as yet unanswered scientific question (Jackson et al., 2011).

All of these scientific and regulatory investigations into the potential impacts of unconventional oil and gas activities on water resources have been directly challenged by gas-drilling companies and their trade organizations (America's Natural Gas Alliance, 2012). This has created an atmosphere of scientific mistrust and conflicting information and thus raises public doubts regarding the real versus perceived risks of hydrofracking (Klemow, 2012). Adding to this public uncertainty and confusion are conflicting scientific reports from federal agencies, state agencies, and researchers about potential risks (Boyer et al., 2011). An acute example of such conflicting research information can be seen in the case of a large chemical spill in Bradford County on April 19, 2011. The incident took place in Leroy Township when the wellhead valve flange connection failed at the Atgas 2H gas well owned by Chesapeake Appalachia, LLC (SAIC Energy et al., 2011). This wellhead failure during hydraulic fracturing into the Marcellus formation resulted in an off-site release (passed the containment system) of over 10,000 gallons of well fluids containing a mixture of materials being used in hydrofracking at the time, as well as waste, or produced, waters. The fluids were contained on the well pad by the afternoon of April 20 (over 12 hours after the initial failure), and the well was under permanent control by April 25. Before they were contained, however, the chemicals broke through the earthen berm containment system, flowed into a freshwater pond and agricultural fields, and eventually flowed into Towanda Creek, a tributary of the Susquehanna River. Amphibians in a nearby pond were found dead after the release (Hrin, 2011).

Two separate reports on the Atgas spill, one done by a private contractor hired by the gas well owner and another done by a federal government agency, provide conflicting findings. The private-contractor report, commissioned and paid for by Chesapeake Appalachia, LLC, the owner of the Atgas well, determined that there was no groundwater or surface-water contamination because of the spill (SAIC Energy et al., 2011). A second report by the ATSDR (2011b), which focused solely on the potential pathways for environmental contamination to affect human health, found that at least one private drinking-water well adjacent to the spill was contaminated, possibly by the chemical spill from the Atgas well. In light of this finding, the ATSDR report went on to say that the agency would be conducting further tests and research to determine the exact cause of the contamination and any possible human health impacts (pp. 20–21). In the meantime, Chesapeake Appalachia maintains that there was "no effect whatsoever" on surface water (Hrin, 2011) and issued a letter to the ATSDR asking it to withdraw its findings (personal communication, anonymous ATSDR staff, Washington, DC, April 2012). If studies like this that sought to document the aftermath of a catastrophic spill can produce such contradictory findings, it is even more challenging to achieve consensus on the long-term and cumulative impacts of hydrofracking and other unconventional oil and gas E&P on human and environmental health.

It is within this contested terrain over best available information and scientific evidence, and mounting public and scientific concern regarding the impact of hydrofracking on human health and the environment, that the 111th Congress (2009a, pp. 99–100; 2009b, p. 109) funded the EPA to conduct a scientific study to investigate the possible relationships between hydraulic fracturing and impacts on drinking water.

The EPA Hydraulic Fracturing Study and Its Regulatory Context

In its 2011 "Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources," the EPA set out a methodology for conducting a scientific assessment of the risks to drinking water created by hydraulic fracturing techniques used in the oil and gas industry across the US (US EPA, 2011). Congressional hearings in anticipation of the beginning of this EPA study revealed a great deal of disagreement over the appropriate boundaries of the study plan, with oil and gas corporations and their lobbying organizations pushing for an extremely narrow focus that would treat many potential avenues for water pollution as outside of the appropriate reach of the EPA's analysis (112th Congress, 2011). In the end, the EPA still settled on a fairly narrow scope for the study plan, with exceptions in their analysis of surface spills, the fate of wastewaters, and a preliminary environmental justice screening (Table 1).

The EPA hydraulic fracturing study will specifically evaluate the impact of hydraulic fracturing on groundwater and surface-water resources by looking at large-volume surface-water withdrawals, surface spills from chemical mixing, injection and fracturing processes, surface spills of

Table 1. Study questions and activities outlined in the US Environmental Protection Agency's (2011) "Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources"

Study questions	Study activities
Water acquisition: What are the potential impacts of large-volume water withdrawals from groundwater and surface water on drinking-water resources?	1. Analysis of existing data including input from public and private stakeholders, including academic researchers
Chemical mixing: What are the possible impacts of surface spills on or near well pads of hydraulic fracturing fluids on drinking-water resources?	2. Prospective and retrospective case studies selected based on input from agency staff, public, and private stakeholders
Well injection: What are the possible impacts of the injection and fracturing process on drinking-water resources?	3. Scenario evaluation using computer risk modeling
Flowback and produced water: What are the possible impacts of surface spills on or near well pads of flowback and produced water on drinking-water resources?	4. Laboratory studies to understand the fate and transport of chemical contaminants
Wastewater treatment and waste disposal: What are the possible impacts of inadequate treatment of hydraulic fracturing wastewaters on drinking-water resources?	5. Toxicological summaries of available toxicological information and, as necessary, toxicological screening studies of chemicals specific to hydraulic fracturing

flowback and produced (waste) waters, and inadequate treatment of wastewaters. To do this, they will (1) review and analyze existing data; (2) conduct prospective and retrospective case studies in North Dakota (Killdeer and Dunn Counties), Texas (Wise County), Pennsylvania (Bradford, Susquehanna, and Washington Counties), and Colorado (Las Animas and Huerfano Counties) to look at existing and potential concerns and provide regional context for the larger EPA study (US EPA, 2011, pp. 58–63); (3) use computer risk modeling to evaluate scenarios, including an environmental justice screening to answer the research question of whether hydraulic fracturing occurs disproportionately in or near communities with environmental justice concerns; (4) conduct laboratory studies to understand chemical fate and transport; and (5) review existing toxicological information and, as necessary conduct new toxicological screenings. One of the publicly anticipated outcomes of the EPA study is a greater understanding of the role that federal environmental regulations could play in governing hydraulic fracturing, specifically related to the conservation and protection of water quality and human health. However, as explained later in this article, regulatory and institutional barriers currently in place may prevent the EPA from acting on its findings even after further risk analysis.

The funding and planning of the EPA's current hydraulic fracturing study comes 11 years after another study on hydraulic fracturing specifically related to coal-bed methane E&P was begun (US EPA, 2000). This study used existing peer-reviewed research, interviews, site visits, and public comments in its analysis. The EPA did not conduct its own independent scientific investigations of the potential risks. In 2004, it concluded that no evidence existed of groundwater contamination from hydraulic fracturing. Given these findings, the EPA determined that no further scientific or technical assessment regarding the risks of hydraulic fracturing was necessary (US EPA, 2004). Beginning in 2005, the use of hydraulic fracturing in unconventional oil and gas E&P, including shales, tight sands, and coal-bed methane and specifically in onshore industry operations, was exempted from important environmental laws, including the Safe Drinking Water Act, Clean Air Act, Clean Water Act, Resource Conservation and Recovery Act, and the Comprehensive Environmental Response, Compensation, and Liability Act (104th Congress, 2005). Political controversies surrounding these exemptions are perhaps one of the primary reasons behind public anticipation that study results will provide regulatory insights. However, a closer look at the EPA's regulatory jurisdiction may foreclose such an outcome.

According to the laws and regulations that are under the EPA's jurisdiction, the EPA is only required to conduct a comprehensive analysis of the environmental, societal, and human health *benefits* associated with implementing new regulations under the Toxic Substances Control Act (US EPA, 2012b, Table 3-1). The other legislation that must be considered when looking at regulating hydraulic fracturing (and from which the process is currently exempt)—the Clean Air Act, Clean Water Act, Safe Drinking Water Act, Resource Conservation and Recovery Act, and the Comprehensive Environmental Response, Compensation, and Liability Act—have varying requirements for cost-benefit analysis based on specific statutory language in each separate piece of legislation. But perhaps the largest barrier to conducting comprehensive social and ecological analyses of environmental regulations is that, as currently codified, none of the EPA's enabling legislation creates room for a prior analysis of the costs (especially nonmonetary) to the environment, society, or human health if proposed new regulations *are not* implemented (US EPA, 2012b, Table 3-1). So from a strictly regulatory and institutional perspective, the lack of a clear statutory mandate to conduct rigorous and holistic cost-benefit analyses means that the EPA's hydraulic fracturing study alone should not be expected to provide justification for or against regulation but instead can only narrowly identify the best available science that could be used to consider such regulation.

Another important point about the EPA's regulatory reach in relation to the hydraulic fracturing process and drinking water is that the EPA has no authority to regulate pollution as it relates to private drinking-water wells (104th Congress, 1996). In the US, the use of private water wells versus publicly managed drinking-water sources depends on geography (Macintyre, Ellaway, and Cummins, 2002). That is, in most rural areas and in areas farther from urban population centers, a greater percentage of the population relies on private water wells. These private wells are under the purview of state and local governments, and in most cases the water quality from these private wells is the responsibility of private landowners. So, despite growing scientific evidence that chemical contamination of private water wells from spills and underground migration of hazardous chemicals might contaminate groundwater (Warner et al., 2012), the EPA is not authorized to regulate that risk and can step in only if an industrial accident resulting in documented damages has been reported [as was the case in Dimock Township and in the Atgas well site accident in Leroy Township (personal communication, anonymous EPA staff, Pittsburgh, Pennsylvania, November 2011)]. So, regardless of the EPA study's findings regarding water quality and human health, a regulatory vacuum still exists regarding protection of drinking-water quality in predominately rural areas across the US.

A Framework for Incorporating Societal Concerns into the Assessment of Hydrofracking

What the previous overview of environmental studies, government investigations, and regulatory barriers and responsibilities reveals is a focus on short-term or reactionary impact studies and a lack of integration, or even recognition, of social, community, and health science information with environmental data, by either the scientific community or the regulatory community. For the past 30 years, however, social scientists have been conducting research that seeks to characterize broad trends in the local and regional social impacts of rapid economic development projects in the US, including conventional and unconventional oil and gas development (for examples, see Albrecht, 1978; Brown, Dorius, and Krannich, 2005; Cortese and Jones, 1977; England and Albrecht, 1984; Freudenburg, 1981; Gilmore, 1976; Kassover and McKeown, 1981; Krannich and Greider, 1984; Park and Stokowski, 2009; Smith, Krannich, and Hunter, 2001). This diverse literature on social impacts contains important findings about community responses to rapid change, mental health, crime, economic indicators, public perceptions, rural poverty, and many other specific topics that are relevant to understanding and assessing the societal costs of unconventional oil and gas development.

What is missing from this social science research, and of most relevance to the EPA's hydraulic fracturing study, are comparative studies between localities and regions, neighborhood and family-scale longitudinal studies, studies of the long-term consequences of these types of development on cultural resources and community-based resource economies, and studies that specifically look at the impacts of unconventional oil and gas development and the process of hydrofracking on social and community change and public health outcomes. Besides studies of occupational worker health and safety and studies with communities living near downstream oil and gas facilities (e.g., processing plants, ethane crackers, refineries) (Epstein and Selber, 2002; Greenberg, Waksman, and Curtis, 2007), we know far less about the social and public health impacts related to unconventional oil and gas exploration, drilling, and transportation facilities, especially the impacts of unconventional extraction processes using hydrofracking. The framework proposed here offers a way to explicitly identify and characterize societal concerns about unconventional oil and gas development and incorporate those local concerns into environmental assessments.

In their assessment of hydraulic fracturing and drinking water (US EPA, 2000, 2011), the EPA is using a traditional translation role of risk characterization that was first outlined in 1983 by the US National Research Council's (NRC) Committee on the Institutional Means for Assessment of Risks to Public Health in the report "Risk Assessment in the Federal Government: Managing the Process," or more commonly referred to as the "Red Book" (NRC, 1983). The Red Book approach to risk assessment says that risk characterization is a final translational step that involves development of a concise estimate of adverse effects on a given population (p. 3).

In 1996, the NRC's Committee on Risk Characterization released "Understanding Risk: Informing Decisions in a Democratic Society," which recommended a new way of approaching risk assessment—a method that involves an iterative analytic-deliberative process in characterizing risks during problem formulation and throughout all stages of assessments dealing with hazards to public health, safety, and the environment (NRC, 1996). In this process, illustrated in Figure 1, *analysis* refers to the systematic application of theories and methods from natural science, social science, engineering, decision science, logic, mathematics, and law, and *deliberation* refers to the methods used for building understanding or reaching consensus through public and cross-sectoral discussion, reflection, persuasion, and other forms of communication (p. 30).

It is an iterative process in that deliberation frames the analysis, and analysis informs the deliberation through various feedback loops. It can also be a slower process and involves longer commitments from participants. At every step of the process, all public and private parties concerned are engaged in deliberation and analysis. However, carrying out risk assessments on controversial subjects with high public visibility, such as hydraulic fracturing and drinking water, by using this 1996 iterative analytic-deliberative process of risk characterization, instead of the current Red Book process, could in the end lead to better risk decision making and long-term risk management (NRC, 1996, p. 166).

One reason why this analytic-deliberative approach to risk is so effective is that it makes room for deliberation about the more broad-ranging concerns that local communities, the public, and the private sector have regarding the risks

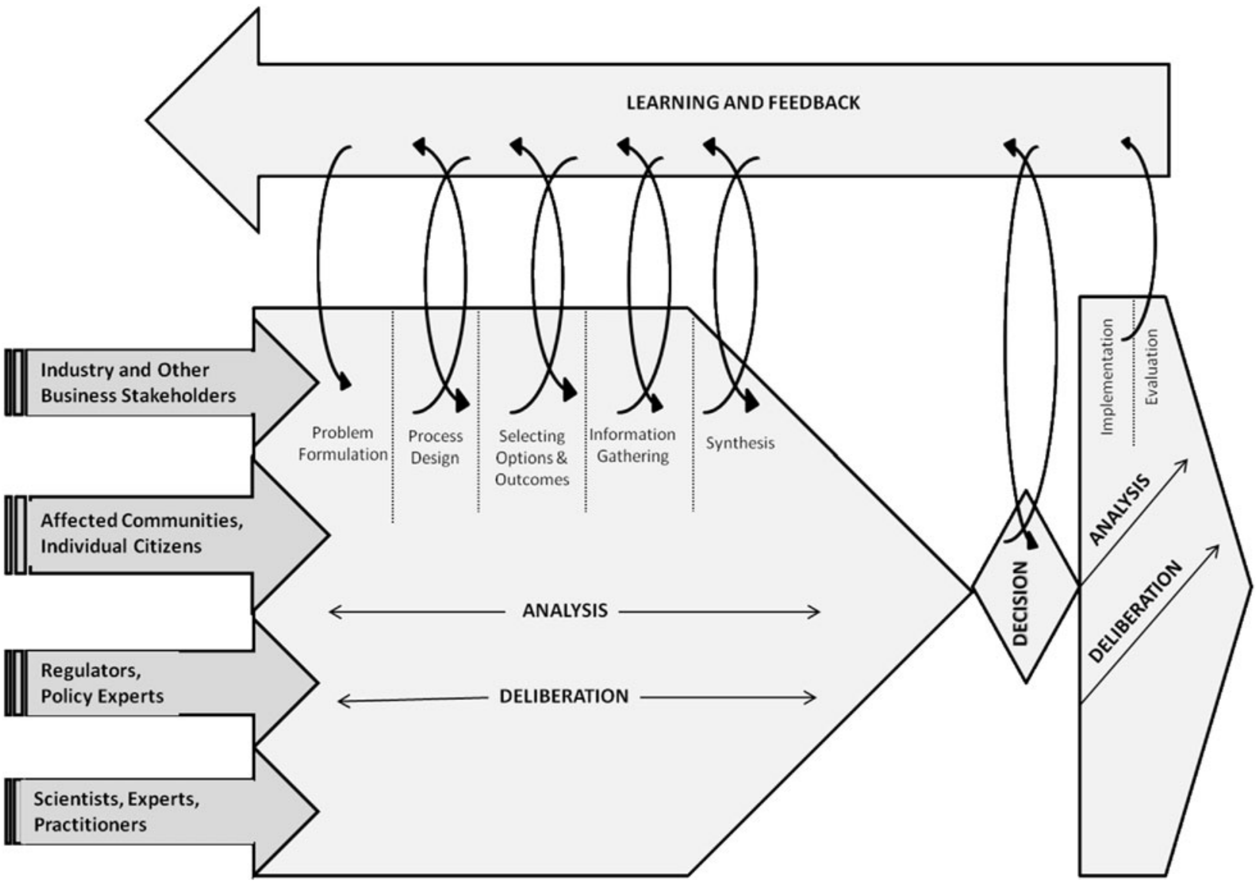

Figure 1. A schematic representation of an iterative analytic-deliberative process for conducting environmental risk assessments. Adapted from National Research Council (1996, p. 28, Figure 1-2).

and uncertainties around such complex issues as hydrofracking. This ensures that assessments are not focused just on those concerns solely related to science and regulation, which in some cases may have less value to public policy and perceptions (Fiorino, 1990). These broader deliberations are necessary in order to make explicit the risks and uncertainties facing social, community, and human health factors, or overall societal costs, as they may relate to E&P operations over various temporal and spatial scales. The concept of societal costs used here is borrowed from the literature and research in the disciplines of human resource management, public health, community psychology, natural resource economics, and environmental law studies (for examples, see Lengnick-Hall and Lengnick-Hall, 1988; MacKenzie, Bartecchi, and Schrier, 1994; Revesz, 1999; Sagan, 1972) and includes similar terms and concepts like human or social capital, human factors, health indicators, human assets, hidden costs, external costs, transaction costs, indirect costs, and damages (Liljas, 1998; Sen, 2000).

What sets the societal costs in this framework apart from some of these other intellectual traditions and conceptualizations is that these costs are not intended to be assessed by quantitative measurement alone. Instead, societal costs by using this framework are assessed at local, community scales and across various temporal scales recognizing environmental, regulatory, and industry variables (including current and historic pollution issues or legacy wastes) and measured with various qualitative, and sometimes quantitative, criteria.

Figure 2 shows a conceptual model of how these local community interactions among social, community, and human health (societal) factors and the addition of unconventional oil and gas E&P operate. The types of societal factors identified in Figure 2 are for illustrative purposes only. In application of the framework, these societal factors would be identified through the aforementioned analytic-deliberative process. This open process goes hand in hand with this conceptual model because it ensures that all the

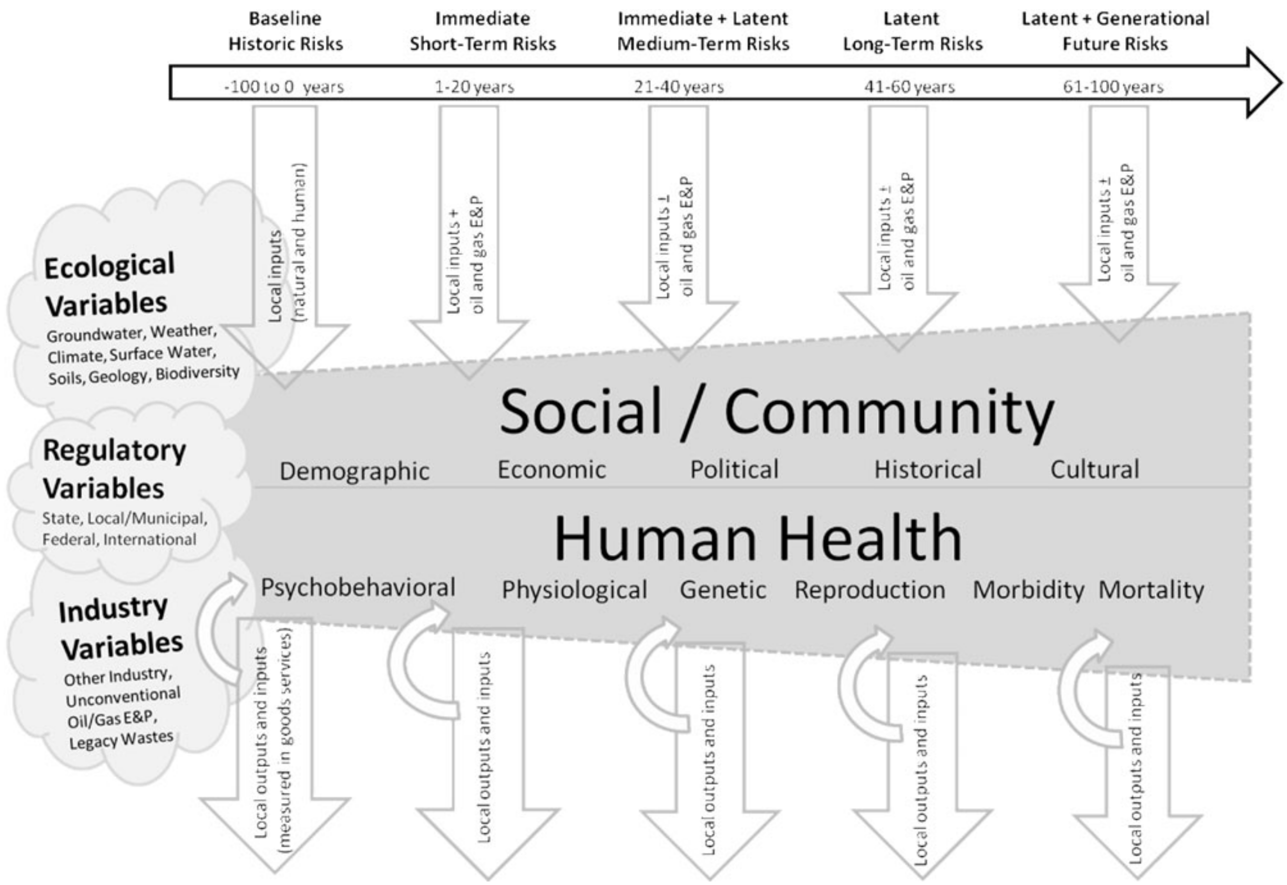

Figure 2. Conceptual model showing the local community interactions among societal factors (social, community, and human health), environmental, regulatory, and industry variables, and *inputs* (*top arrows*) along a cumulative time line from 0 to 100 years. The *outputs* (*bottom arrows*) that emerge as a result of these interactions can be used to measure societal costs. E&P, exploration and production.

relevant factors, variables, and inputs and outputs are identified throughout the risk-assessment process and into the risk-management phase.

Figure 2 illustrates also the relationships across time of societal factors, ecological, regulatory, and industry variables, and the different inputs. These inputs include local natural and human resources (e.g., local population fluctuations, local land uses and products, and cultural and occupational knowledge), as well as the inputs resulting from nonlocal oil and gas E&P (e.g., population from outside local area, industry-specific land uses, and employment training). It is important to note that this is a cumulative model that along each temporal step involves adding or subtracting (±) inputs as the oil and gas E&P activities expand (*boom*) and contract (*bust*) at the local level. The model assumes that societal costs are cumulative, and that ecological, regulatory, and industry variables, and inputs fluctuate over time. Recognizing the changing and cumulative nature of these relationships also recognizes that there are differences between immediate and latent risks, and that there are intergenerational implications of making decisions in the present that may impact future generations in unexpected or unknowable ways (Revesz, 1999).

The final result of these temporal interactions among societal factors, ecological, regulatory, and industry variables, and local and nonlocal oil and gas inputs are new outputs related to local goods and services (e.g., population increases, employment, income, infrastructure, land uses and products, and emergency services), some of which may create new inputs that further interact with the societal factors. The important point is that these outputs, whether qualitative or quantitative, can be measured with regard to their costs and benefits to society. For example, local outputs can be evaluated with a special emphasis on how newly created goods and services impact nonmonetary and qualitative aspects of social, community, and health factors, including access and enjoyment of outdoor activities, food and water security, and various other measures of overall well-being.

A Case Study: The EPA's 2011–14 Hydraulic Fracturing Study

In the current EPA assessment of hydraulic fracturing and drinking water, great emphasis is placed on initial scoping via public meetings and public dissemination of the assessment's results; however, the iterative analytic-deliberative process proposed here goes beyond these public outreach activities and seeks to answer broader concerns about risks raised by all interested and concerned segments of the local population, as well as by public and private organizations. The framework described earlier is not just about stakeholder and public outreach and involvement in designing the research plan and in reporting research results, which are the main focuses of the EPA's hydraulic fracturing study (US EPA, 2011, pp. 3–5, 7). It is also about seeking engagement of the public throughout problem formulation and the research activities and well into management of the risks. It involves incorporating new community-based and scientific research questions that will address broader public concerns about risk throughout the research and assessment process. In the case of the EPA study, that could mean that some community-based research questions would have less to do with hydraulic fracturing as it relates to drinking water and more to do with traffic, noise, air pollution, and other community concerns.

While the EPA's proposed environmental justice assessment is a first step in recognizing and understanding how certain communities may be more at risk than others to water-quality problems from hydraulic fracturing, it falls short by not anticipating the broader deliberations on hydraulic fracturing that should be considered in risk characterization regarding the societal costs to local communities and issues of environmental equity and fairness that are embedded in the current regulatory system. For example, differences in how private versus public water systems are regulated, or a lack of regulations regarding private water wells, could be considered an environmental justice concern since small rural communities across the US are affected disproportionately and different standards on water quality are applied. Since these different standards are tied to sociodemographic characteristics and urban versus rural land uses, they do not allow for equal protection of and access to clean sources of drinking water for rural people. Access to clean drinking water is a serious environmental justice issue that affects all communities where hydraulic fracturing or other industrial processes with the risk of contaminating water supplies are taking place.

Instead of proactively addressing known environmental justice issues regarding hydraulic fracturing and access to clean drinking water, the EPA study uses an environmental justice analysis based on indexing of US Census and American Community Survey data at the county level (US EPA, 2011, pp. 53–55). While this is an acceptable approach to an assessment of environmental justice in fairly stable and urban populations, the use of this survey data carries with it assumptions that do not apply to the types of rural communities with hydrofracking activities. One of these assumptions is that the US Census and American Community Survey statistical data realistically reflect demographic trends in rural geographic areas with unconventional oil and gas E&P. However, most areas with this development have smaller populations, are traditionally agricultural (meaning that the US Department of Agriculture's survey data may be more appropriate), and are experiencing such fluctuations in their local populations that statistical information on demographic changes may be either exaggerated or not captured at all or in an appropriate time frame (Lizik, 2006). In addition, census data alone will not capture the local impact of the oil and gas industry's transient workforce, mostly composed of young to middle-aged men who may claim permanent residence in one state but live and work for weeks, months, or years in communities where onshore oil and gas E&P projects are taking place (O'Rourke and Connolly, 2003). This transient workforce may significantly influence the sociodemographic (including economic) characteristics of a county or region even if their presence is not counted in census surveys. For example, the population and one-parent, one-income households might increase as a result of short-term sexual relationships between local female residents and the mostly male workforce, or local income and business tax payments might increase through workers' spending of personal income or company funds at local restaurants, lodging accommodations, gas stations, and other local establishments.

A more useful approach to designing and conducting the environmental justice analysis of hydraulic fracturing would be first to identify and understand local social change processes that are unique to the oil and gas industry and local communities with unconventional oil and gas E&P. The proposed framework incorporates this type of locally relevant social change information into all steps of the risk assessment, from problem formulation through analysis to risk management. This more localized, context-specific approach to environmental justice, coupled with regulatory analysis of the current institutional barriers to environmental equity and fairness, would more appropriately answer the question of whether hydraulic fracturing disproportionately occurs in or near communities with environmental justice concerns.

The EPA's study plan also includes doing *prospective* (before hydrofracking takes place) and *retrospective* (after hydrofracking takes place) case studies in different counties across the US. This, too, is a laudable first step toward understanding how local communities are impacted from a baseline condition to short and medium timescales. However, it does not satisfy urgent unanswered questions about the societal and human health risks and uncertainties borne by local communities both cumulatively and over long-term and generational timescales. For example, it does not ask important questions about how hazardous chemicals that may be used in hydraulic fracturing and that make their way into surface water, groundwater, air, or soil could affect the development of unborn children and adolescents, as well as women of childbearing age, both in the local communities with oil and gas development as well as in downstream communities or communities where workers have a full-time residence and raise their families (Cooper and Kavlock, 1997). In fact, the risk of exposure among workers and their families who may not live in the communities where these case studies are being conducted, or who live there for only short periods before moving back to more permanent residences in another state, is never mentioned in the EPA's study plan. There is also no recognition of the role that other social or environmental factors may play in increasing a local population's susceptibility to disease if chemical contaminants are present in their water or air. For example, in local communities with oil and gas development where we have evidence that sexually transmitted infections have increased (Witter et al., 2010), how might this affect physiological or emotional stress levels, immune responses, and exposure to hazardous chemicals in air, water, or food?

The justification given for not including the aforementioned types of risk in the EPA's study plan is that they are beyond the plan's scope, which is to evaluate the impact of hydraulic fracturing on drinking water. This, however, is an overly narrow approach to conducting a risk-assessment study on such a complex industrial process that involves environmental and human factors. As a result, the EPA study as currently designed will be limited in its utility for informing public policy or in managing risks posed to local communities. Instead, by using the model of iterative analytic-deliberative process and societal costs proposed here, the EPA could develop an approach to assessing the risks and uncertainties of hydraulic fracturing and drinking-water quality that would be more meaningful to local communities, as well as policy makers.

Discussion and Recommendations

Studies such as EPA's are extremely important for producing generalizable knowledge about the possible impacts of unconventional oil and gas development on environmental and human health, and they can be useful for informing near-term and very specific public policy decisions. This article does not intend to deny the importance of current EPA efforts. Instead, the proposed framework it sets forth should be read and understood as offering an alternative local community-based approach to risk assessment that is not contrary to, but in addition to, the EPA's or any other agency's plan to study the environmental and human health risks of unconventional oil and gas E&P. In general, this framework calls on the EPA and other federal, state, and local agencies to consider following the NRC's 1996 recommendations on iterative, analytic-deliberative processes for risk assessment and to fully incorporate questions about societal costs into their plans, studies, and analyses.

Before this framework can work, though, agencies need to get past the idea of public participation as something an agency does after problem formulation and quantitative measurements. A good first step in that direction would be to take a hard look at how they do what they define as *public participation* and, if necessary, reverse and reconfigure one-way flows of communication and decision making to develop more deliberative, engaged, transparent, and meaningful forms of participation (Fiorino, 1990). This means incorporating an open public process for all aspects of risk assessment from characterization, analysis, and management of risks that uses local community knowledge and qualitative measurements of historic, short-term and long-term, and cumulative risks alongside quantitative measurements of risks. In some cases, this may call for the development of computer models that project future and cumulative risk scenarios, and the development of such models should in turn rely on local community knowledge alongside technical and scientific data (Zartarian et al., 2011). In a practical sense, long-term public participation also means preparing for assessments that may involve a much longer time frame, since deliberation can take more time and the management of risks should be an ongoing process that continues even after scientific research is complete.

This framework also challenges agencies to evaluate critically the current regulatory and institutional context within which they operate. Analysis of the regulatory and institutional context within which government agencies must operate is essential to any risk assessment in order to identify current legislative, financial, and political barriers that may be preventing them from using their regulatory authority. This is particularly important in cases where the risk may be greater for environmental contamination or public endangerment (e.g., the EPA's lack of regulatory authority over private water wells). Where there is evidence of a risk to environmental and human health but such barriers exist, agencies should clearly evaluate the sources of such barriers, assess whether the barriers can prudently be removed, or endeavor to strengthen partnerships with other appropriate government agencies, whether federal, state, or local, that are not subject to such barriers in order to provide appropriate regulatory guidance. By removing regulatory or institutional barriers and strengthening public agency partnerships, government agencies responsible for protecting environmental and human health can ensure that adequate protections and mechanisms for enforcing those protections are instituted in a timely manner.

Use of the deliberative process is particularly relevant for maintaining transparency and therefore some level of trust among all parties by ensuring that feedback, or communication, loops are kept open throughout all stages of risk assessment. This is particularly important when different parties to the deliberations have differential access to power or money that may privilege some participants over others, such as industry participants over local community residents, government agencies over industry participants, or government agencies over local community residents. The roles and intentions of all parties to the deliberations should be articulated and remain open to discussion throughout the risk-assessment process. By following the iterative, analytic-deliberative process recommended by the NRC alongside the conceptual model of societal costs in Figure 2, there is more opportunity for clarification of roles and transparency in interactions among all parties, whether industry, government, or the various nonindustry stakeholders.

From a societal costs perspective, it is essential in evaluating risks related to the unconventional oil and gas industry that industry participants involved in the deliberations identify financial and other personal or institutional conflicts of interest related to the scientific evaluation of risks and possible management decisions. For instance, it may be appropriate and necessary for industry to play a significant role in helping government agencies identify best engineering practices for reducing risks and conducting such scientific research that is necessary to evaluate or test those practices. However, the legal protection of environmental and human health from oil and gas industry practices such as hydraulic fracturing may need to be treated separately since a need for increased protections via regulations or other measures may be seen by industry as a constraint on existing or future oil and gas operations. This becomes a clear financial conflict of interest for the oil and gas industry. The danger is that because of large economic and political power differences between the industry and non-industry stakeholders (e.g., community residents) industry can hold more influence over the process, and the result can be a lack of enforceable protections for environmental and human health. Following the decision-making framework proposed here, with particular emphasis on the analytic-deliberative process, would articulate such conflicts of interest early in the problem-formulation stage and in the development of protective measures thus minimizing or eliminating the involvement of parties that may have a financial or other conflict of interest.

And, finally, in order for government agencies to take the steps necessary to undertake the deliberative processes and comprehensive, multidisciplinary assessments of the societal costs of unconventional oil and gas E&P and hydraulic fracturing that this article calls for, there is a need for greater substantive involvement by nongovernmental scientists and practitioners from a greater diversity of environmental, social, policy, and health disciplines in scoping, planning, analyzing, and managing environmental risks related to unconventional oil and gas in areas with this development. As recognized by Fiorino (1990) and others (De Marchi, 2003; Kasperson, 1986; Rowe and Frewer, 2000), specific regulatory barriers, financial constraints, and political factors facing federal, state, and local environmental agencies can make it difficult for them to carry out the type of public deliberative processes presented here. In some cases, though, lack of subject-matter expertise may be an even greater barrier that could be overcome by increasing the involvement of nongovernment experts at the beginning of assessment planning. What is true of using an open, deliberative process for incorporating local communities and affected stakeholders and their concerns into every step of the risk-assessment process is also true for incorporating the broader scientific and policy research community.

Acknowledgments

I thank several anonymous contributors from federal agencies who provided insight and thoughtful correspondence on the framework proposed and overall direction of this article. All analysis and critique of current risk assessments being planned or carried out by federal agencies are mine alone. Many thanks also to the three anonymous peer reviewers whose thoughtful, detailed comments greatly improved the original draft.

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Submitted May 15, 2012; revised August 14, 2012; accepted August 20, 2012.