Unconventional Gas Development in the USA: Exploring the Risk Perception Issues

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ABSTRACT

Unconventional gas development (UGD) is examined from a risk-perception perspective. Drawing on the risk literature, recent opinion surveys, and case studies of regulation in eight states, we find that UGD is an emerging technology that is likely to be perceived as risky, even though the two most commonly claimed risks, water contamination and induced seismicity, appear to be controllable through competent industry and regulatory practices. Perceived risk is likely to increase as the technology is used more widely in the United States but any public outrage is likely to be attenuated because of perceived benefits and related forms of risk compensation for individuals and communities. The types of triggering events necessary for large-scale social amplification and stigmatization have not yet occurred but organized interests against UGD are becoming stronger and are exerting significant influence. It is too early to determine whether UGD will become stigmatized in the same way that nuclear power and genetically modified foods are now stigmatized in some regions of the world.

Key words: fracking, water contamination, induced seismicity, unconventional gas development, risk perception, public opinion,

1. INTRODUCTION

A "revolution" in the global energy system is underway.[1] Innovators in Canada and the United States have demonstrated that the amount of natural gas that is economically recoverable is vastly larger than previously reported. Instead of running out of gas within several decades, experts now estimate that North America has sufficient recoverable reserves to last hundreds of years. Within a decade, North America could go beyond self-sufficiency in natural gas and become a leading exporter of gas to the rest of the world.

Conventional gas development entails producing gas resources from porous and permeable formations (e.g., sandstones) using traditional production technologies such as vertical boreholes and natural pressures. Significant amounts of natural gas are also trapped in finely-grained sedimentary rock ("shale"). Until recently, producing gas from shale was technically and economically impractical. As gas recovered from conventional fields in North America declined, production rates began a steady downward trend resulting in a rise in natural gas prices in the 1990s. The stage was set for profitable innovation.[2]

George Mitchell, with training in geology and petroleum engineering at Texas A&M, began work on unconventional methods of gas production in the 1970s.[3] He started with a well-known well stimulation process termed hydraulic fracturing or "fracking", and modified it to be applicable for enhancing production from shales.[4] Mitchell's innovations included modifying the composition and volumes of the drilling fluids and discovering new ways of emplacing fracturing fluids into the shale formations.

Fracking was not new; it was initially developed in the 1940s and was widely used by industry before Mitchell tweaked it. Helped along by research from the U.S. Department of Energy, Mitchell was in a race with competitors who were trying to unlock shale gas with different types of drilling fluids (e.g., expensive foams and gels). Mitchell's technique was far less expensive because the fluids are largely water and sand, with only a tiny percentage of chemicals.[5]

When Mitchell sold his company to Devon Energy for $3.5 billion in 2002,[6] his innovation was combined with an entirely different innovation that engineers at Devon were perfecting: directional or horizontal drilling. Before Devon's contributions, it had already been demonstrated that conventional vertical drilling techniques could be modified to include "slant drilling", meaning that the wells could be drilled at an angle to a location not directly beneath the surface location. Directional drilling goes a step further allowing for the drilling of a hole that is initially vertical but can be "steered" to become completely horizontal. Directional drilling is very useful for offshore locations, but it also boosts the commercial viability of on-shore shale gas production. A single borehole can contact much more of the shale reservoir than a conventionally drilled vertical hole. Additionally, directional drilling can tap gas that is trapped under sensitive areas (e.g., shallow lakes) and other cultural and technical barriers on the surface. The cost of horizontal drilling may be more than double that of vertical drilling, but the production of hydrocarbons has, on average, been 3.2 times larger when horizontal drilling is employed.[7] Directional drilling offers an additional advantage: the number of wellsites necessary to tap a large reservoir is much reduced, meaning less forest fragmentation and surface disruption than if only vertical drilling were used to tap the reservoir.[8]

In this paper, we define "unconventional" gas development (UGD) as the use of advanced drilling and completion techniques including horizontal drilling and staged, high volume hydraulic fracturing. In mass media reports, opinion surveys (cf. Appendix A), and the social science literature, UGD is often referred to loosely as "fracking". This use of the term can lead to confusion since fracking, a word widely used within the industry, refers only to the reservoir stimulation technique of hydraulic fracturing.[9] Therefore, it is important to understand that opponents of UGD often criticize "fracking" when they really mean any or all aspects of UGD.

Our goal in this paper is to explore public opinion on UGD from the perspective of the risk perception literature in light of current scientific understanding of the actual risks of UGD. Based on the risk literature, we treat UGD as an emerging technology and discuss whether this technology is likely to become stigmatized. Could the technology become so unacceptable to the public that it is prohibited (literally or practically) in the way that nuclear power and genetically modified foods have become stigmatized in some parts of the world?

The paper draws several conclusions and calls for some additional research. First, based on the risk literature, there is ample reason to predict that public risk perception of UGD will become elevated, though it is too early to assess how severe the stigmatization will become. In local communities where UGD might be undertaken, the prediction is less clear because a variety of community benefits from UGD could dampen the severe stigmatization that might occur if only the potential risks of UGD were salient. Second, formation of public opinion about UGD is at an early stage of development, since large percentages of respondents indicate that they are not familiar with the phenomenon. This degree of ignorance suggests ample opportunity for both proponents and opponents of UGD to make their case in the years ahead. Third, we found that risk concerns about water quality and seismicity are currently the most prevalent concerns articulated about UGD. The current state of scientific understanding about these issues suggests that these risks should be manageable through industry best practices, regulation, and an improved safety culture within the industry. We hypothesize that, for some of the well-organized opponents of UGD, these two concerns may not be as central as they appear today, and that deeper concerns about the growth of UGD in North America (e.g., delay of renewables and fears centered on linkage of fossil fuel usage to climate change) have yet to be fully articulated. On the other hand, for local community residents who live with UGD on a day-to-day basis, we hypothesize that the dominant concerns are nuisances (traffic, congestion, noise, odor, and changes in community character) that are common to many intensive forms of industrial development. We therefore we suggest additional research to better characterize the risks and benefits of UGD as perceived in key subgroups: local community residents who have experienced UGD, local community residents who have experienced public debates about UGD, leaders of local community groups who favor or oppose UGD, state regulators (politicians and career staff) who are responsible for governing UGD, and organized environmental and business advocacy groups who are stimulating much of the advocacy, pro and con, about UGD.

2. METHODS

We began by identifying four bodies of risk literature that shed light on whether an emerging technology will be perceived as risky and become stigmatized in the eyes of the public. We apply each of those literatures to UGD. We then review a large number of public opinion surveys in the United States to examine trends in perceptions of UGD. Our work builds on the review of public opinion polls done by Wolske, Hoffman, and Strickland.[9] Using their framework as a basis, we identify additional surveys conducted between 2010 and 2013 that focus on 'fracking' or hydraulic stimulation. Some have nationally representative samples; others focus on specific regions or states. To varying degrees, the surveys address familiarity/awareness, knowledge, attitudes toward UGD, perceptions of risks and benefits, and trust in UGD stakeholders. Third, we draw information from case studies of perceptions of UGD in eight states as reported by the media. In these studies, the actors and along with their positions, as well as actions by state regulatory bodies were compiled. The states include some that have authorized large amounts of UGD (Texas and Pennsylvania), some that have enacted explicit or de facto moratoria (California, Illinois, and New York) and some that are at an intermediate stage of development and regulation (e.g., Colorado, Michigan, and Ohio). Appendix B provides a summary of the regulatory actions portion of the eight case studies. The details of these studies are not presented in the paper but we drew insights from them about stakeholder concerns, "triggering events" that are stimulating local and state attention, and risk claims that seem to be capturing attention in local and state media sources. Fourth, we examine the stated positions of national and state environmental advocacy groups in policy debates about UGD. We also describe their efforts to persuade the Obama administration to take a more critical posture toward UGD. Finally, we contrast the risk claims and emerging perceptions with a brief review of current scientific understanding of the extent of two major concerns about UGD: water contamination and induced seismicity. As is often the case with emerging technologies, scientific understanding of the risks of UGD is evolving as the technology is implemented and as real-world experience is accumulated. Thus, it is crucial not to see the state of the science as fixed and indeed we strive to highlight some of the key uncertainties that remain.

3. PREDICTING PERCEPTIONS AND STATE-OF-PLAY ON PUBLIC OPINION OF UGD

In the 1970s social scientists became fascinated with the public's variable reactions to the development of nuclear power and other emerging technologies that are potentially hazardous to human health, safety and the environment.[10] Technologists became particularly interested in this literature since they were baffled by the fact that nuclear power was far safer than coal on a death-per-kilowatt-hour basis but much of the public was more inclined to tolerate coal than nuclear as a source of electricity.[11]

The key insight of social scientists was to look beyond the technical estimates of risk and focus on some of the qualitative aspects of the potential hazards that could be associated with an emerging technology.[12] Four bodies of risk research shed light on the formation of risk perceptions associated with emerging technologies and their potential hazards.

3.1 Psychometric Framework of Risk Perception

The first body pinpointed a variety of qualitative factors that are relevant in predicting public perception of risk.[13] Those factors include:

--familiarity, as less familiar hazards tend to raise public perception of risk (e.g., traffic crashes are more acceptable because they are familiar);

--voluntariness, as risk perception is elevated when a hazard is seen as being imposed upon people without their consent (e.g., when a community is informed by the state that a maximum security prison will be located near their town center);

--individual controllability, as perception of risk rises when individuals feel that they cannot control the risk (e.g., the greater concern about airplane crashes compared to car crashes, since most drivers think they are more competent than the typical driver);

--catastrophic potential, as perceived risk rises when a large amount of damage (human or ecological) could occur at one time and location, even if it is of low probability;

--natural versus human-induced hazards, with greater senses of guilt associated with those that are induced by human activity;

--impact on children or future generations, with heightened concerns associated with hazards that could impact people who are seen as less capable of defending themselves (e.g., children, pregnant women, and people who are not yet born).

Each of these factors may be of independent importance but combinations of such factors may be especially potent in elevating the perception of risk. The concept of "dread" has multiple meanings but it is sometimes used to refer to hazards that trigger a variety of these undesirable characteristics (e.g., unfamiliar, catastrophic, and impact on future generations). Risk-perception specialists sometimes refer loosely to a technology's "outrage factor" being linked to combinations of perceived-risk factors.(14)

With respect to public opinion on UGD in the United States, the general public is unfamiliar with UGD and uncertain of its opinion toward this technology.

Public awareness of and attitudes toward UGD have been the most popular variables in the opinion surveys conducted to date. A common finding from these surveys is that large percentages of respondents, sometimes a majority, have never heard of fracking or hydraulic fracturing or are not familiar with the practice. The CBS News/New York Times National Survey conducted in March 2011 showed that sixty-four percent of the respondents have heard not much or nothing about fracking.(15) The Energy Poll of the University Texas at Austin carried out in September 2013 revealed that more than half of the respondents were not familiar with fracking. (16)

There is some evidence that awareness has increased in recent years and that levels of awareness are greater in states/communities where UGD is underway or where permission to begin UGD has been hotly debated. Public opinion polls in New York State and North Carolina provide vivid illustrations of rising familiarity with the issue of fracking (Cf. Appendix A: Table 1).

The lack of the familiarity with the issue leads to respondent uncertainty about attitude toward UGD.(17) The attitudes of those who have heard of fracking and formed an opinion are almost evenly divided between opponents and supporters. A striking feature about the attitudes toward UGD is the intensity of the opinions - those opposing are likely believe fracking to be a "bad thing", the supporters are convinced it is a "good thing". (17)

A few surveys contain knowledge questions about UGD (Cf. Appendix A: Table 2). Not surprisingly, many respondents offer factually incorrect answers, since this is a topic where lay knowledge is neither broad nor deep. One survey found that only 51% of respondents were aware that "fracking" is a process that extracts natural gas from the earth, not coal, diamonds, or silicon.(18) Only about half of respondents were aware that energy production in the United States has increased in recent years. (19) About one third of the respondents do not connect hydraulic fracturing to natural gas but to other fossil or renewable sources of energy.(16)

When asked about possible adverse aspects of UGD, respondents are most likely to indicate concerns about water contamination (groundwater, drinking water and/or surface water). Surveys also evaluate public's opinion toward other adverse aspects that include possible harms from the chemicals used in the process, the amount of water used, habitat loss, destruction of wildlife, earthquakes, gas releases, air pollution, and increased road traffic. The surveys usually present a respondent with a list of formulated concerns that are to be evaluated. Thus, the results of the surveys show a broad variation of intensities of public concerns toward various risks associated with UGD. However, when asked about their top of the mind associations with regard to fracking, the majority of the respondents is uncertain, with "don't know" being the most common answer (58% of respondents).[17] Furthermore, when asked to rate their energy-related concerns, the respondents provide "the impact of hydraulic fracturing on natural environment" with the lowest rating among ten energy-related concerns and "the price of gasoline" with the highest rating. [16]

The review of public opinion shows that, at the moment of this writing, the national public is largely unfamiliar and uncertain in its attitude toward fracking whereas UGD does not present a major energy-related concern in public opinion. If UGD becomes seen as a risk factor for water contamination and/or earthquakes, it could provoke virtually all of the risk-perception factors discussed above. From a risk-perception perspective, the possibility of drinking water contamination from UGD merits special investigation because it raises concerns about voluntariness, human responsibility, and a possible harm to children and future generations. After all, some of the chemicals used as drilling fluids in UGD are carcinogens or exhibit other troubling forms of toxicity.[20] If earthquakes are caused by UGD, it also raises the specter of a possible catastrophe, the clustering of multiple casualties in space and time. In conclusion, as UGD activity spreads to a larger number of states and as people become more aware of it, there is ample reason to predict that perceptions of risk will increase.

3.2 Risk governance

A second body of risk research focuses on the decision making processes that relate to technological development/diffusion and risk management. The question this research addresses is whether the democratic aspects of risk governance are properly respected.[21]

A democratic approach to risk governance implies an open and informed process. Concerns tend to elevate when information about potential hazards is kept secret by business and/or government, when citizens are not provided an opportunity to participate in safety determinations about a technology, when the safety issues are so complex that only a small number of specialized experts can understand the issues and participate meaningfully in risk management, and when the experts in a field are seen as "too close" (e.g., through financial consulting arrangements) to companies that are working to commercialize a potentially hazardous technology.[22]

Risk concerns can be attenuated when a competent regulatory system operates to provide a forum for expression of risk concerns and a vehicle to minimize risks through legally-binding rules.[23] The success of regulation in managing risk varies widely depending on factors such as the resources made available to the agency, the extent of the regulator's legal authority, the political independence of the agency's leadership, the technical competence and credibility of regulatory staff, and the vigilance of enforcement activity in the field.

A component of the case studies was the documentation of the various regulatory changes in eight states (Texas, Pennsylvania, New York, California, Colorado, Michigan, Illinois, Ohio) where UGD is underway or is under consideration (see Appendix B). In the United States much of the regulatory authority over oil and gas operations – especially the issuance of site-specific permits for UGD – resides in state agencies, not in the federal government or local communities. At the state level there is a wide variety of legislation that differs both in scope and depth.[24] The state decision-making processes related to UGD are not particularly reassuring from a risk-communication perspective, which is in part why many state regulatory systems are being reformed.[25] The amount of fiscal resources available to state regulators for monitoring and inspections is also highly variable. The degree of independence of state regulators from the industry is often questioned. In some states, the primary mission of the responsible agency is development of natural resources rather than assuring safety and environmental protection. Expertise about UGD is highly concentrated in the oil and gas industry, and thus it is difficult for regulators, NGOs, academics and community leaders to participate in technical discussions on an even footing with industrial experts.[26] A partial veil of secrecy about the chemical composition of drilling fluids, which is justified by industry on the grounds of confidential business information, is only beginning to be eased.

Few opinion surveys elicit public opinions about the appropriate level of regulation. Those that do, indicate that there are shortcomings in both federal and state regulation. The majority of respondents believe that more regulation on UGD is desirable to reduce risk (Cf. Appendix A: Table 3). In a survey covering residents of New York State residents were asked about local government authority to control natural gas development. Sixty-one percent of the respondents agreed or strongly agreed with some local government authority over UGD. [27]

The federal government does not play a major role when it comes to issuing permits for UGD but the major national environmental groups, which are quite critical of state regulation of UGD, would prefer to see a national regulatory system, perhaps through EPA. The two presidents of the United States during the period of rapid growth of UGD (2000-2013), George W. Bush (Republican) and Barack Obama (Democrat), have been strongly committed to a positive framing of fracking and further development of the industry. They have set a climate in Washington, DC that makes it difficult for organized critics of UGD to accomplish their “anti-fracking” agenda through national legislation or regulation.

President Obama has claimed as a personal achievement the rapid growth of natural gas production during his presidency.[28] His administration has recently gone further by offering to help China and India undertake UGD and by approving several export terminals where liquefied natural gas will be shipped to countries in Europe and Asia. Obama recognizes the safety concerns about UGD but believes they can be addressed.

In his 2012 State of the Union Message, for example, Obama pledged “to take every possible action to safely develop” natural gas resources.[29] This pro-gas stance has not softened since his re-election in November 2012. In a 2013 speech in Pittsburgh on climate change, Obama forcefully rejected some of the key arguments made by activists against UGD. He also emphasized: “We will keep working with the industry to make drilling safer and cleaner.”[30]

In their campaign to regulate or prohibit UGD, anti-fracking groups are not bashful about confronting Obama. In August 2013, for example, 500 anti-fracking protesters appeared at a town hall event in Binghamton, New York where President Obama delivered a speech on energy. On the day of Obama’s speech, a full-page ad in the Binghamton Press and Sun led with the theme: “President Obama: Stop Covering Up the Science on Fracking.” The ad featured phrases such as “can’t be done safely”; “poisons water and people”; and “spells disaster for climate.” The activity was orchestrated by the national group Food and Water Watch and a state group New Yorkers Against Fracking.[31]

President Obama’s pro-UGD position is a source of considerable irritation among organized environmental advocates, as they were important allies in his election campaigns for Senate in Illinois and for the Presidency. Documentary filmmaker and activist Josh Fox – who says he has supported Obama and agrees with him on many issues -- put it bluntly: “Obama is the guy who presided over more fracking than Bush". He criticized Obama for ignoring the "largest grassroots movement on the environment in several decades."[32]

When faced with the contrasting accounts of UGD as a risk problem, trust emerges as a central variable for public acceptance.[33] The relative degree of trust in the key actors (innovators, businesses, regulators, environmentalists, and academics) plays an important role in perception of risk, with the amount of trust/mistrust influenced by a variety of contextual considerations that vary from one situation to another.[34] Among the stakeholders involved in risk communication on UGD, the scientific community and the environmental organizations are perceived as the most trustworthy by the public (Cf. Appendix A: Table 4). As important as trust is, it is difficult to generalize about how to create and maintain it, or recreate it when it is lost.[23]

3.3 Risk Compensation and Benefits of Technology

The perception of benefits from an emerging technology can influence how the public perceives the acceptability of the technology's potential risks.[35] Radiation from medical technology is seen as more acceptable than radiation from nuclear power operation because people perceive the benefits of medicine more readily than they perceive the benefits of energy.[36] Nor will all of the technological risks faced by a community be judged to be unacceptable. If a community is seen as garnering benefit from a technology (e.g., directly through local jobs or indirectly through tax revenues that finance schools, parks and hospitals), then a potentially hazardous technology may have a greater chance of public acceptance. If the benefits from the technology are accrued in a different community than the risks of the technology, then the prospects of conflict are heightened.

The benefits of UGD are tangible, significant, and to some extent distributed in the communities where drilling activity occurs. Property owners can earn royalties from UGD and they form an important pro-development group within a community where UGD is proposed. There are obvious employment benefits during the period when exploration and development of gas resources occur. As prices of natural gas have declined in the USA due to UGD, a more indirect yet long-term benefit of UGD has occurred: the location of large gas-intensive manufacturing facilities in close proximity to communities where UGD occurs. Those manufacturing plants bring high-paying jobs and more tax revenue to local communities. And most regulatory systems include some form of tax or fee on UGD that generates revenues that are often directed (at least partially) toward communities where UGD occurs. Thus, for a variety of reasons, we should expect that risk perception of UGD will be attenuated to some extent by community recognition of benefits. In economically depressed areas, the economic stimulus provided by UGD may be seen as highly desirable; in already prosperous suburban communities, the possible stimulus provided by UGD may be seen as a less significant consideration.

As for the surveys of public opinion about fracking, they tend to address the potential risks in more detail than the potential benefits. Those few national surveys that address public perceptions of benefits from UGD include assessments of perceptions about job creation, energy independence, and positive effects for local and national economies. State-level surveys provide more information about perceived benefits, especially job creation (direct and indirect).

The economic benefits of UGD have already been widely felt and communicated in Texas, Arkansas, Oklahoma and Pennsylvania. And the recent efforts to launch UGD in Ohio, Illinois, and Michigan have been advocated based on the economic-stimulus argument. As salient as it is, the job-creating argument is not always decisive. The asbestos, lead, and tobacco industries did not win in the long run making this argument and the coal industry is now having a difficult time winning with the argument in the face of concerns about climate change and other forms of pollution.

3.4 Triggering events, amplification, and degrees of stigmatization

Finally, social science research highlights the importance of triggering events that spawn media coverage, enhancement of public concerns, and a cascading of negative effects (physical, psychological and economic) and various degrees of stigmatization.(37) Examples of dramatic triggering events/locations include the Chernobyl and Fukushima accidents in the case of nuclear power, the Love Canal and Bhopal incidents in the case of industrial chemicals, and the Valdez and Deep Horizon oil spills in the case of oil.(38) A theory of "social amplification" of risk highlights a variety of factors – some intensifying and some attenuating – that help explain the extent of amplification of public concern.(39) Thus, two hazards of equal actuarial importance can have widely different social ramifications, depending on how events occur, how they are publicized, and how the process of social amplification unfolds.(40)

The social science research has also demonstrated that stigmatization of technology based on risk perception is not a symmetric phenomenon.(41) It is far easier to raise risk concerns about an emerging technology than it is to prove that an emerging technology is completely safe (e. g. the Yucca Mountain nuclear waste repository). Once a technology has become stigmatized in the public eye, it is quite difficult to remove the stigma, even if new scientific evidence presents powerful evidence of safety.(42) Both the artificial sweetener saccharin and silicone breast implants were able to counter some early – and erroneous -- claims of risk that led to prohibitions but the process of de-stigmatization can be quite challenging and time consuming.

It is far too early to assess how much UGD will become stigmatized in the USA. It seems likely that the extent of stigmatization can be lessened over time based thorough site-specific monitoring under a strict regulatory system. However, considering the risk-perception factors and the recent trends in public opinion toward fracking, a process of stigmatization is already under way. One of the most interesting findings about attitude is that in split samples, respondents who are exposed to the term "fracking" report more negative attitudes than respondents who are not exposed to the term "fracking," even though the survey questions were otherwise identical.(43)

To date there has been no major triggering event about UGD that has led to large-scale public concerns. There have been publicized cases of residents in Texas and other states claiming that contamination of their drinking water with methane was causally related to UGD. EPA originally backed these claims but later backed off. There have been a series of potentially UGD-related earthquakes in Oklahoma, Arkansas, Ohio, and Texas that might be considered mild triggering events. Furthermore, the emotional storytelling of the movies Gasland (2010) and The Promised Land (2012) have sparked widespread concern about UGD, in part because they feature community residents who are convinced that the methane contamination of their drinking water was induced by UGD.

In the long run, the perceptions of laypeople may be influenced by the positions of one of the most trusted groups in society: the scientific community. Science provides evidence, that people couple with their own values, to create their specific positions and opinions. A review the state of scientific knowledge on the issues of water contamination and induced seismicity follows.

4. STATE OF THE SCIENCE: WATER CONTAMINATION AND INDUCED SEISMICITY

As with most significant industrial developments, there are impacts (positive and negative) on individuals and communities when a new technology is commercialized. Such stakeholders will have different relationships with UGD as a function of their physical proximity to the development processes, and as a function of their perceptions of the risks and benefits engendered by gas production. The degree of proximity often shapes the types of risks that are perceived and to what extent their potential negative consequences could impact a given group of stakeholders.

Within the scientific and technical communities, the fundamental understandings of most of the processes that would be applied to a given site of UGD are established. For example, the basic science of fluid flow in a porous and fractured media or the mechanics of fault failure in an earthquake are well understood. The complexity arises in the application of these basic understandings to specific geographical settings where UGD risks may exist. When the understandings of the basic physical and chemical processes are used to explain observed phenomena in a specific UGD setting, complexities and uncertainties are inevitable.

Those impacts that have been specifically cited as risks associated with UGD include a) impacts to water resources, both the surface and groundwater systems, b) the surface and subsurface of the land and associated ecosystems, and (c) the local and global qualities of the air. A recent report by the international Risk Governance Council provides a detailed itemization of risks that could potentially occur within these three domains of impact.[25] Based on the concerns that have been articulated by various groups, scientists, local residents and governmental agencies, two appear to be the most prominently associated with UGD: the potential for degradation to water resources and the possibility of inducing seismic events.

Given that concerns about water quality and earthquakes are among the most prominent risk concerns raised about UGD, it is appropriate to review the current state of scientific understanding on these concerns. We do so here, drawing from well-accepted sources within the scientific community. However, as is often the case with emerging technologies, scientific understanding of the risks of UGD is evolving as the technology is implemented and as real-world, site-specific experience is accumulated. Thus, it is crucial not to envision the state of the science as fixed but rather a best approximation at the time of the understanding of the systems, with the inherent uncertainties that remain.

4.1 Water contamination

UGD can cause the contamination of water resources through five principle mechanisms: 1) fluid migration around the production casing of a well, 2) improper closure and plugging of an abandoned well, 3) direct “communication” (flow of contaminants) between the reservoir (during and/or after production) and the groundwater resources, 4) surface spills and leaks near the wellsite or during transport to and from the wellsite, and 5) improper handling and disposal of wastes.

The first three activities are mostly risks of groundwater contamination while the latter two are primarily risks to surface waters. In the first three cases, the constituents that can contaminate groundwater include naturally occurring hydrocarbons (such as methane) and brines, and in some cases fluids that were introduced through the hydraulic stimulation process. In the latter two, the contaminants can again be naturally occurring hydrocarbons (not methane) and produced waters but especially the liquid and soiled components of fracturing fluids and solid materials generated by the drilling process.

The drilling of a borehole into the deep subsurface creates pathways for fluids that naturally are isolated from the shallow groundwater system to potentially flow and mix with potable water supplies. This is a long established concern and has been addressed by the industry and regulatory bodies for many years. Casing and cementing requirements are designed to artificially re-establish the isolation of the two types of waters and such measures have been effective in protecting groundwater.[44] Although there are decades of experience in groundwater protection, the techniques used to effectively case and cement productive wells continue to evolve with the advances in drilling and completion technologies.[45] In general, the consensus in the technical and regulatory communities is that with the appropriate implementation of best practices and regulatory compliance, risks to water resources via loss of borehole integrity can be effectively managed and minimized.

As with the securing the integrity of the borehole with appropriate casing and cementing protocols, the procedures for effectively plugging and abandoning a formally productive or dry borehole have also been long established. As the pathways of potential contamination of water resources are similar, the plugging procedures established by the regulatory community use techniques established to isolate deep formation fluids from the surface and subsurface sources of drinking water. To be effective, the techniques for removing casing and injection of cement into the borehole must be both technically appropriate and executed properly. In this context, the technical consensus is that, when done correctly, water contamination risks stemming from improperly plugged wells can be minimized.

A more recent theory is that there could be direct hydraulic communication between the productive reservoir and the groundwater resources, and that fluids and gases in the reservoir could contaminate the groundwater by migrating thousands of feet vertically through fractures induced in the subsurface. The key question is whether hydraulic stimulation could create pathways for fluids and gases in the reservoir to contaminate the groundwater or whether the process could enhance natural pathways that already exist. The source of the energy that would be needed to propagate such fractures might be the increased pressures resulting from a hydraulic stimulation. As large-scale UGD did not begin until around 2000, this is a potentially new phenomenon that is uniquely associated with gas production from unconventional reservoirs. There is not the multi-decadal, widely- established experience with assessing this risk and managing its potential occurrence.

From industry's perspective, there are two fundamental technical constraints that diminish the possibility of this being a risk. In many cases the challenge of the industry is to localize enough fluid pressure to propagate fractures within the reservoir (hence the use of "staged" hydraulic stimulations to concentrate adequate pressure). Thus, the possibility that fractures could be propagated thousands of feet out of the reservoir up to the groundwater aquifers is implausible. Fisher[46] demonstrated that in the Barnett Shale of Texas the "height" of the induced fractures was well within the target zone and significantly distal to the groundwater system. In Arkansas tests with tracers show that fluids travel no more than a few hundred feet after stimulation, even when measurements are taken a year after hydraulic stimulation. Nor should it be assumed that developers have any interest in creating fractures outside of the reservoir. The purpose of hydraulic stimulation is to enhance the permeability within a reservoir, thereby to promoting the flow of hydrocarbons to the wellbore. A hydraulic fracturing technique that creates fractures that go out of the zone of interest is not in the best interest of the operator. If such an event takes place, often the result is communication with another nearby saline reservoir, which greatly reduces the prospects of successfully producing hydrocarbons. So even if mechanically the potential exists to create a fracture system to the groundwater aquifer, it is not in the commercial interest of the developer to do so.[47]

A different, and perhaps more plausible scenario would be that hydraulic stimulations enhance a naturally occurring fracture system. As essentially all hydrocarbon traps naturally leak micro amounts of oil and gas, these pathways do exist on some scale. The gas and oil resources initially developed within the United States in western New York (gas from the Marcellus Shale) and oil in north central Pennsylvania (Devonian sandstones) were both discovered by drilling into natural hydrocarbon seeps. Segregating the effects of new developments of hydrocarbons by UGD techniques from those that occur naturally is difficult. Methane occurrence in groundwater is not a new and unique phenomenon associated with the advent of UGD.

Researchers are trying to use a variety of techniques to decipher the ultimate origin of such gas occurrences, including methane contamination of drinking water.[48, 49] In several cases, (Dimock PA and Pavilion WY) where complaints have been lodged, the EPA has declined to associate what was initially thought to be a connection between methane in groundwater and hydraulic stimulation.[20] To date, there has not been a clearly established relationship of this risk to water resources with UGD.

On the other hand, risks to surface water and groundwater by spills or leaks on the surface is a well-documented and significant risk associated with many industrial activities. UGD entails the handling of large volumes of fluids and solids during the drilling and completion processes, including some materials that are hazardous, toxic, radioactive, and carcinogenic.[50, 51, 45] The risk to water resources stem from leakage or spilling of fluids and solids from holding tanks, tanker trucks, pits and other containers. To evaluate the frequency of these events, necessary considerations include the rate of development at a site, modes of transportation (pipeline, truck, etc.), and storage mechanisms (pits, tanks, etc.). Frequency may be further delineated by the failure rate associated with each technology (e.g., single- versus double-walled tanks). The volume of a release is inversely proportional to the likelihood it will occur.[52] Lower-probability (high-volume) releases are associated with catastrophic failures of containment mechanisms and accidents during transportation. The magnitudes of the potential impacts from contamination depend on the concentration and chemical composition of the contaminants in the water. As with other industrial processes that create potential exposures, the application of best practices of materials handling – both on and off the wellsite -- can be used to mitigate the consequences of this risk. Preventing and managing leaks and spills is a constant challenge during UGD but not one that is unique or even especially difficult compared to other such challenges throughout industry.

Drilling and hydraulic fracturing generate considerable solid and liquid wastes that must be disposed of properly. Solid material removed from the subsurface to create the wellbore is collected on the well pad and is known to contain elevated levels of heavy metals and other hazardous materials, including naturally occurring radioactive material (NORM).[45] After hydraulic fracturing, much of the water and fluids remain in the reservoir but there is also significant amount of the injected fluid that returns to the surface as flowback water. It is typically stored at the wellsite in lined pits or vented tanks. The quantity and constituents of the fluid waste streams vary within and across formations, and may be concentrated by treatment processes, but they are expected to contain the chemicals from the fracturing fluids and salts, hydrocarbons, dissolved metals, and NORM from the reservoir. [53, 54]

Disposal options for produced wastes vary depending upon their potential adverse effects on human health, safety and the environment. Disposal of solid or partially de-watered wastes in landfills, on the ground, or by entombment (burial) are current practices. Leachate is the primary risk to surface and groundwater quality. Numerous methods for disposal of waste fluids exist, though not all may be appropriate or viable for a particular project. An arid climate is necessary for evaporating waste fluids, and suitable geologic conditions must be present for deep-well injection of wastes. Properly implemented deep well injection of various types of waste (EPA Classes 1-V [I–V or 1–5?]) has been documented to be effective in protecting groundwater.[44]

Constituent concentrations and volumes determine both the effectiveness and cost of treatment processes for waste fluid disposal. Conventional sewage treatment plants designed for organic and biological constituents are not effective at removing metals and other dissolved solids common in gas industry wastewater[55] and should not be used for disposal of wastes from UGD. Illicit dumping of wastes on the ground and into rivers by waste haulers has been observed[56], but is not known to be widespread.

Precautions must be taken to ensure wastes are disposed safely and permanently. With proper planning and oversight, low-level hazardous wastes may be disposed in a manner that poses negligible risks to surface and ground water resources. Depending on the amount of waste generated and its constituents, specialized facilities may be required to lower the risks to acceptable levels. Opportunities for the beneficial reuse of drilling wastes may also decrease waste disposal requirements.[57] Waste manifests, or other systems to track the collection and disposal of wastes generated from UGD, enhance transparency and are viable deterrents to illicit practices.

4.2 Induced Seismicity

The injection, or withdrawal, of fluids from the deep subsurface can cause the fracturing of rocks, resulting in seismic events. This can happen in three ways in association with UGD: 1) during the process of stimulating reservoirs with hydraulic fracturing, 2) during the withdrawal of gas and water during production, and 3) during the reinjection of flowback fluid and/or wastewater into deep wells for permanent disposal. In the first two cases, the seismicity that results occurs within the producing reservoir and is of a very low magnitude. It is termed "micro-seismicity" and includes events with moment magnitudes of -1 to -4 Mw. Generally, seismic events need to exceed a moment magnitude of 2 to be felt.[50]

First, the process of hydraulically stimulating a reservoir exceeds the strength of the rock by design and creates fractures to connect the reservoir with the wellbore. The process results in many "micro-seismic" events that can be recorded, but cannot be felt at the surface. Therefore the risks to people and property are minimal.

Second, as water and gas are removed from a reservoir, there exists the possibility that the decrease in volume of the pore system will be associated with micro-fractures within the reservoir and also result in micro-seismic events. These events are analogous to those described previously, but are generally of an even smaller moment magnitude.[50]

The third way in which seismicity can be induced is by the injection of produced water into a saline aquifer located in the deep subsurface. Such aquifers are hydraulically isolated formations with a high storage capacity. Deep-well injection of wastes is attractive to both developers and regulators because the technology has been demonstrated to effectively accommodate the large volumes of fluids that are produced during UGD. A significant difference between this source of seismicity and the previous two is that the volume, duration and rate of fluid injection can be much higher (tens of millions of gallons, for months, at high rates). If the volume or rate of injection is high enough, and if a critically stressed fault lies within the elevated pressure window, the stress caused by the pressure of the injected fluids will exceed the strength of the rock in either the storage reservoir or in the overlying/underlying seals. Thus, deep-well injection may cause fracturing of the rock that is large enough to result in a felt seismic event. The magnitude of the earthquakes are proportional to the area of fracturing; the larger the area, the larger the magnitude of the seismic event, the larger the risk.[50] Depending upon the type of bedrock and unconsolidated materials in the region that are shaken, varying amounts of damage are possible at the surface.

The risk of induced seismicity from deep-well injection is minimized by existing rules and industry practices that restrict the volumes and injection rates to levels that result in pressures that are below fracture pressures. Zoback[58] has recommended a set of five basic practices that could be used by operators and regulators to safeguard an injection operation from inducing seismicity when pumping fluid into the subsurface: 1) avoid injection into active faults and faults in brittle rock; 2) formations should be selected for injection (and injection rates should be limited) to minimize pore pressure changes; 3) local seismic monitoring arrays should be installed when there is a potential for injection to trigger seismicity; 4) protocols should be established in advance to define how operations will be modified if seismicity is triggered; and 5) operators need to be prepared to reduce injection rates or abandon wells if triggered seismicity poses any hazard.

When compared to other risks associated with UGD, induced seismicity is considered relatively low in both probability and severity of damages and thus is not a major focus of most oil and gas operations. A recent report by the USA National Academy of Sciences[59] on induced seismicity states "The process of hydraulic fracturing a well as presently implemented for shale gas recovery does not pose a high risk for inducing felt seismic events and injection of disposal of waste water derived from energy technologies into the subsurface does pose some risk for induced seismicity, but very few events have been documented over the past several decades relative to the large number of disposal wells in operation".[50]

5. CONCLUSIONS AND FUTURE RESEARCH NEEDS

Based on our review of the previous investigations of both the explanations and examples of risk perception, communication and management, we have found that there is ample reason to predict growing public concerns about risk as UGD expands throughout the United States. The prediction is based not on actuarial evidence of dangers from UGD but on the basis that the potential hazards of UGD (e.g., water contamination and induced seismicity), can trigger a variety of qualitative factors that are known to elevate risk perceptions. Those factors include unfamiliarity, involuntary assumption of risk, lack of personal control over risk, catastrophic potential, hazards linked to human activity (as opposed to nature)-, and potential impacts on children, the unborn and future generations. Currently, the general public is unfamiliar and undecided about its opinion toward UGD, though attitudes are more favorable in some states than in others. A widespread social amplification of concerns has not occurred with UGD because the types of triggering events (e.g., Chernobyl in the case of nuclear power) which are necessary for severe amplification and stigmatization have not occurred. Without a large-scale triggering event, it may be difficult for opponents of prohibition to accomplish their objectives of prohibition or extended moratoria. But even if an event were to occur, the extent of stigmatization will influence the degree of inhibition of UGD.

We have also found that the decision making processes that govern UGD, while rapidly under refinement, are not reassuring to all stakeholders. The number of experts in the field of UGD is relatively limited, and they are employed primarily in the industry that seeks commercial gain from UGD.

Numerous state regulatory bodies that govern UGD are underfunded and some lack the needed statutory authority. In the absence of a strong federal regulatory system, the effectiveness of risk governance depends on fifty state regulatory systems that are variable in structure, authority, expertise, resources, and responsiveness to public and industry concerns. These shortcomings in the regulatory entities are likely to become reflected in indicators of trust (and mistrust), which will fuel the demand for stricter regulation (e.g., this pattern has already played out in Pennsylvania, where regulation has intensified).

The positions of environmental organizations are important because they are perceived as a trustworthy source of information on UGD by segments of the public. However, the role of national environmental organizations in the public debate is complex. They currently seek moratoria on UGD until the risks are better understood, or at least enactment of more stringent regulation of the industry than is currently practiced but in reality such groups may have deeper concerns. Future research should explore whether the fundamental concerns of national environmental organizations are about the impact of UGD on the uncertain future of renewable energy, the uncertain long-term impact of UGD on climate change,[60] or an intrinsic dislike for the way that UGD proceeds by intentional human perturbation of the earth (a position long held in regards to all forms of oil and gas development).

Future research should also explore the nature of local community concerns about UGD. We hypothesize that they overlap only partially with the primary concerns of national environmental organizations. When residents live with UGD on a day-to-day basis, the dominant concerns may not be water pollution or earthquakes but a variety of nuisances (traffic, congestion, noise, odor, and changes in community character) that are related to any intensive form of industrial development. If the primary concerns of local communities and national environmental NGOs are not completely aligned, then the proponents of UGD must recognize the complexity of the situation. The concerns of local communities may be more readily addressed (e.g., through careful planning and compensation for nuisances) than the concerns of national NGOs.

APPENDIX A

Overview of the surveys on public opinions of unconventional gas development (UGD), commonly referred to as "fracking". Surveys from 2010-2013, reported as of January, 2014*

Table 1: Public awareness of and attitudes toward "fracking" [(9), (61), (62)]

Sponsor	Dates	Location	Sample Size	Awareness	Attitude
The University of Texas at Austin – Energy Poll	Sep 2013	USA	2,144	40% familiar , 53% not familiar	base: 861 38% oppose, 38% support
The University of Texas at Austin – Energy Poll	Mar 2013	USA	2,113	42% familiar , 52% not familiar	base: 889 41% oppose, 45% support
The University of Texas at Austin – Energy Poll	Sep 2012	USA	2,092	35% familiar , 59% not familiar	base:726 41% oppose, 41% support
The University of Texas at Austin – Energy Poll	Mar 2012	USA	2,371	32% familiar , 63% not familiar	base: 752 36% oppose, 48% support
Pew Research Center	Sep 2013	USA	1,506		44% favor, 49% oppose
Pew Research Center	Mar 2013	USA	1,501		48% favor, 38% oppose
Pew Research Center	Mar 2012	USA	1,503	26% have heard a lot, 37% a little, 37% nothing	base: 1038 52% favor, 35% oppose
Quinnipiac University Polling Institute	Dec 2013	USA	2,692		45% support, 36% oppose
Yale Project on Climate Change Communication and the George Mason University Center for Climate	Sep 2012	USA	1,061	54% have heard nothing at all/a little, 22% some, 9% a lot, 13% don't know	base: 495 59% think fracking is a bad thing, 42% think it is good.
Rasmussen Reports	Mar 2012	USA	1,000		57% favor, 22% oppose, 21% unsure
CBS News	Dec 2012	USA	1,176	59% have heard/read at least something	
CBS News/New York Times Poll	Mar 2011	USA	1,382	35% have heard a lot/ some, 64% not much/nothing	
Public Policy Institute of California (PPIC)	Sep 2013	CA	1,703		53% oppose, 32% favor
Public Policy Institute of California (PPIC)	Jul 2012	CA	2,500	54% have heard at least a little about fracking, 46% nothing at all	base: 1350 42% favor, 46% oppose, 12% don't know
Quinnipiac University Poll	Nov 2013	CO	1,206		51% support, 34% oppose
Reilly Center for Media & Public Affairs Manship School of Mass Communication Louisiana State University	Feb 2012	LA	731	questions with random use of the word "fracking" 36% have heard a lot/some, 18% not much, 45% nothing so far	39% state should encourage drilling, 35% not encourage, 27% don't know

				questions with random description of process without the word "fracking"	
				38% have heard a lot/some, 15% not much, 46% nothing so far	52% state should encourage drilling, 35% not encourage, 13% don't know
University of Michigan & Muhlenberg College	May 2013	MI, PA	839	MI: 415	
				40% heard a lot, 42% heard a little, 17% never heard	54% strongly support/ somewhat support, 35% somewhat oppose/ strongly oppose
				PA: 424	
				46% heard a lot, 40% heard a little, 13% never heard	49% strongly support/ somewhat support, 40% somewhat oppose/ strongly oppose
The Elon University	Sep 2013	NC	701	39% have heard a lot, 38% a little	base: 548
					47% support, 40% oppose
The Elon University	Mar 2012	NC	534	16% paid a great deal of attention to the news about fracking, 23% some, 20% not very much, 25% none at all, 16% don't know	22% strongly oppose/ oppose, 22% support/ strongly support, 57% don't know enough about it
The Elon University	Nov 2011	NC	529	6% paid a great deal of attention to the news about fracking, 14% some, 15% not very much, 38% none at all, 27% don't know	
Siena College - Siena Research Institute	Jan 2013	NYS	1,154	60% heard a great deal/some, 22% not very much, 18% nothing	40% support, 40% oppose, 20% not enough info/don't know/no opinion
Siena College - Siena Research Institute	Aug 2012	NYS	671	63% heard a great deal/some, 22% not very much, 15% nothing	39% support fracking in upstate NY, 38% oppose, 23% don't know
Siena College - Siena Research Institute	May 2012	NYS	766	66% heard a great deal/ some, 14% not very much, 20% nothing	37% support fracking in upstate NY, 36 oppose, 27% don't know
Siena College - Siena Research Institute	Nov 2012	NYS	822	63% heard a great deal/ some, 20% not very much, 17% nothing	42% support fracking in upstate NY, 36 oppose, 22% don't know
Siena College - Siena Research Institute	Oct 2012	NYS	750	66% heard a great deal/ some, 21% not very much, 12% nothing	42% support fracking in upstate NY, 36 oppose, 23% don't know
Siena College - Siena Research Institute	Sep 2011	NYS	808	51% heard a great deal/ some, 23% not very much, 24% nothing	
Siena College - Siena Research Institute	Jul 2011	NYS	813	47% heard a great deal/ some, 24% not very much, 28% nothing	
Quinnipiac University Polling Institute	Jun 2013	NYS	1,075		46% support, 44% oppose
Quinnipiac University Polling Institute	Apr 2013	NYS	1,404	69% have heard of fracking, 30% have not	42%support, 46% oppose
Quinnipiac University Polling Institute	Mar 2013	NYS	1,165		39% support, 46% oppose
Quinnipiac University Polling Institute	Dec 2012	NYS	1,302	66% have heard of fracking, 33 have not	44% support, 42% oppose
Quinnipiac University Polling Institute	Sep 2012	NYS	1,589	65% have heard of fracking, 34% have not	45% support, 41 % oppose
Quinnipiac University Polling Institute	Jul 2012	NYS	1779	62% have heard about fracking, 37% have not	43% support, 44% oppose
Quinnipiac University Polling Institute	Dec 2011	NYS	1,143	59% have heard about fracking, 39% have not	44% support, 45% oppose

Quinnipiac University Polling Institute	Aug 2011	NYS	1,640	57% have heard about fracking, 42% have not	47% support, 42% oppose
Marist College Institute for Public Opinion	Feb 2013	NYS	814		39% oppose, 40% support, 21% unsure
Marist College Institute for Public Opinion	Oct 2011	NYS	1,030		42% oppose, 36% support, 22% unsure
Marist College Institute for Public Opinion	Jul 2011	NYS	600		37% oppose, 32% support, 31% unsure
Marist College Institute for Public Opinion	Apr 2011	NYS	941		41% oppose, 38% support, 21% unsure
Quinnipiac University Polling Institute	May2012	OH	1,069	64% have heard about fracking, 35% have not	64% support, 29% oppose
Quinnipiac University Polling Institute	May 2012	OH	1,610	59% have heard about fracking, 40% have not	64% support, 29% oppose
Resources for the Future	2013	PA, TX	1,600		most respondents support shale gas development
Mercyhurst University - The Mercyhurst Center for Applied Politics	Sep-Oct 2013	PA	579	74% aware, 26% not aware	base: 426 49% favor, 28% oppose
Mercyhurst University - The Mercyhurst Center for Applied Politics	Sep-Oct 2013	PA	426	70% aware, 30% not aware	base: 298 55% favor, 27% oppose
Muhlenberg College Institute of Public Opinion, University of Michigan Ford School of Public Policy	Oct-Nov 2011	PA	525	12% have been following the debate on fracking very closely, 36% somewhat closely, 26% not too closely, 25% not at all	
The University Texas at Austin - Energy Institute	2011	Barnett Shale Area (TX)	1,500	50% somewhat aware/ very aware, 50% not very aware/ not aware at all	

Table 2: Public knowledge on "fracking" as related issues (9), (61), (62)

Sponsor	Dates	Location	Sample Size	Knowledge
The University of Texas at Austin – Energy Poll	Sep 2013	USA	861	65% connect fracking to natural gas, 46% to oil, 18% to hydro, 8% to coal, 4% to wind, 3% to solar, 2% to nuclear
The University of Texas at Austin – Energy Poll	Mar 2013	USA	889	70% connect fracking to natural gas, 50% to oil, 16% to hydro, 8% to coal, 3% to wind, 2% to solar, 3% to nuclear
Pew Research Center	Sep 2013	USA	1,506	48% correctly say that U.S. energy production is up in recent years, 34% correctly attribute it mainly to greater oil, coal and natural gas production
Pew Research Center	March 2013	USA	1,006	51% knows that "fracking" is a process that extracts NG, not coal, diamonds or silicon from the earth

Table 3: Public perceptions of risks and benefits of "fracking" [(9), (61), (62)]

Sponsor	Dates	Location	Sample Size	Risks	Benefits
The University of Texas at Austin – Energy Poll	Sep 2013	USA	861	46% water contamination, 16% negative effects from the chemicals used in the process, 10% habitat loss and the destruction of wildlife, 7% earthquakes, 3% air quality/emissions, 1% increased road traffic, 1% other, 17% are not concerned about fracking	
The University of Texas at Austin – Energy Poll	Mar 2013	USA	889	40% water contamination, 18% negative effects from the chemicals used in the process, 8% habitat loss and the destruction of wildlife, 9% earthquakes, 3% air quality/emissions, 1% increased road traffic, 4% other, 17% are not concerned about fracking	
The University of Texas at Austin – Energy Poll	Sep 2012	USA	726	41% water contamination, 13% negative effects from the chemicals used in the process, 9% habitat loss and the destruction of wildlife, 9% earthquakes, 5% air quality/emissions, 1% increased road traffic, 2% other, 19% are not concerned about fracking	
Yale Project on Climate Change Communication and the George Mason University" Center for Climate	Sep 2012	USA	969	"top of mind"-associations: 7% environment (e.g. water contamination, pollution)	"top of mind"-associations: 3% economic effects in general or energy supply/independence issues (e.g. job creation, increases in domestic oil and gas supply)
The Harris Poll	Sep 2012	USA	2,562	66% potential benefits of natural gas outweigh the risks, 17% vice versa, 17% not sure	
The Harris Poll	2011	USA		64% potential benefits of natural gas outweigh the risks, 17% vice versa, 18% not sure	
The Harris Poll	2009	USA		66% potential benefits of natural gas outweigh the risks, 14% vice versa, 20% not sure	
Rasmussen Reports	March 2012	USA	1,000	14% believe it is impossible to develop shale oil reserves in the United States while still protecting the environment, 63% believe it is possible to develop these energy reserves without doing environmental damage, 23% not sure	
Deloitte	Nov 2011	USA, mature shale plays, newer shale plays	1,730	general population: 663	
				58% water contamination, 49% impact on the surface land, 34% amount of water used, 29% earthquakes or tremors, 29% air emissions, 3% other env concerns	48% boosting local economies, 47% job creation, 47% energy independence, 43% cleaner air, 43% boosting the national economy
				mature shale plays: 573	
				62% water contamination, 57% impact on the surface land, 37% amount of water used, 41% earthquakes or tremors, 26% air emissions, 4% other env concerns	48% boosting local economies, 49% job creation, 47% energy independence, 46% cleaner air, 44% boosting the national economy
				newer shale plays:494	

				57% water contamination, 56% impact on the surface land, 33% amount of water used, 22% earthquakes or tremors, 30% air emissions, 2% other env concerns	44% boosting local economies, 47% job creation, 45% energy independence, 43% cleaner air, 46% boosting the national economy
University of Michigan & Muhlenberg College	May 2013	MI, PA	839	MI: 415	
				18% water contamination, 14% health issues, 8% ground water/well contamination, 8% pollution/chemicals, 6% environmental damage (general), 2% earthquakes, 2% general risks, 1% gas releases/ air pollution, 6% no risks or minimal risks, 1% the risk is not fracking, 1% other, 25% not sure/don't know	27% energy independence, 20% investments and jobs, 15% reduces carbon emissions, 13% reduces energy costs for consumers and industries, 3% increases the amount of tax revenue, 13% no potential benefits
				PA: 424	
				34% water contamination, 9% ground water/ well contamination, 9% health issues, 6% environmental damage, 6% gas release/ air pollution, 3% pollution/ chemicals, 2% general risks, 1% earthquakes, 4% no risks or minimal risks, 1% the risk is not fracking, 1% other, 18% not sure/don't know	28% investments and jobs, 27% energy independence, 13% reduces energy costs for consumers and industries, 11% reduces carbon emissions, 4% increases the amount of tax revenue, 8% no potential benefits
Cornell University Survey Research Institute	2012	NYS	800	32% quality of life in the communities impacted by fracking will get better, 45% get worse, 23% stay the same	
Cornell University Survey Research Institute	2011	NYS	800	27% revenues that would come from fracking outweigh any risk of contaminating the drinking water, 52% the risk of contaminating the drinking water outweighs any revenues that would come from fracking, 21% do not know enough about drilling	
Cornell University Survey Research Institute	2010	NYS	800	25% revenues that would come from fracking outweigh any risk of contaminating the drinking water, 53% the risk of contaminating the drinking water outweighs any revenues that would come from fracking, 22% do not know enough about drilling	
Siena College - Siena Research Institute	Jan 2013	NYS	1,154	unacceptable risk of contaminating drinking water: 49% agree, 18% disagree; unsafe gas & chemicals come to surface: 46% agree, 20% disagree; too dangerous/unsafe levels of methane release: 41% agree, 20% disagree	generate much needed jobs for NY: 61% agree, 16% disagree; economic benefits for Southern Tier communities: 55% agree, 18% disagree; only way to obtain abundant supply of gas: 28% agree, 31% disagree
Quinnipiac University Polling Institute	Apr 2013	NYS	1,404	54% think that fracking will cause env damage, 29% don't know	72% think that drilling will create jobs
Quinnipiac University Polling Institute	Dec 2012	NYS	1,302	50% think that fracking will cause env damage, 33% don't know	78% think that drilling will create jobs
Quinnipiac University Polling Institute	Sep 2012	NYS	1,589	48% think that fracking will cause env damage, 37% don't know	81% think that drilling will create jobs
Quinnipiac University Polling Institute	Jul 2012	NYS	1779	53% think that fracking will cause env damage, 34 don't know	75% think that fracking will create jobs
Quinnipiac University Polling Institute	Dec 2011	NYS	1,143	55% think that fracking will cause env damage, 31 don't know	75% think that fracking will create jobs

Quinnipiac University Polling Institute	Aug 2011	NYS	1,640	52% think that fracking will cause env damage, 33 don't know	75% think that fracking will create jobs
Marist College Institute for Public Opinion	Jul 2011	NYS	600	33% think that making us more independent from foreign oil is more important than preserving water supplies and the environment, 59% think the opposite, 7% are unsure; 41% think that creating jobs is more important than preserving water supplies and the environment, 51% think the opposite, 8% unsure	
Marist College Institute for Public Opinion	Apr 2011	NYS	941	39% think that making us more independent from foreign oil is more important than preserving water supplies and the environment, 56% think the opposite, 5% are unsure; 41% thinks that creating jobs is more important than preserving water supplies and the environment, 52% think the opposite, 6% unsure	
Quinnipiac University Polling Institute	May 2012	OH	1,069	45% think that fracking will cause env damage, 36% don't know	82% think that drilling will create jobs
Quinnipiac University Polling Institute	Jan 2012	OH	1,610	43% think that fracking will cause env damage, 40 don't know	85% think that fracking will create jobs
Resources for the Future	2013	PA, TX	1,600	most respondents are worried about environmental risks, especially those related to groundwater and surface water, but a fraction are not concerned about any risks. Groundwater is a major concern in both states. Respondents in both states are concerned about risks to surface water, wildlife habitat, and air quality.	
Mercyhurst University - The Mercyhurst Center for Applied Politics	Sep -Oct 2013	PA	426	43% think that fracking poses a significant threat to the environment, 36% do not; 47% think that fracking poses a significant threat to water resources, 34% do not; 39% think that fracking poses threat to human health, 48% do not	37% think that local communities receive significant financial benefits from gas companies, 40% do not; 56% think that fracking brought a significant number of new jobs, 30% do not; 61% thinks that fracking will increase energy independence, 30% do not; 66% think that land owners are making a lot of money due to fracking, 18% do not.
Mercyhurst University - The Mercyhurst Center for Applied Politics	Sep -Oct 2011	PA	298	43% think that fracking poses a significant threat to the environment, 42% do not; 54% think that fracking poses a significant threat to water resources, 30% do not; 44% think that fracking poses threat to human health, 37% do not.	35% think that local communities receive financial benefits from gas companies, 46% do not; 62% think that fracking brought a significant number of new jobs, 25% do not; 59% thinks that fracking will increase energy independence, 26% do not; 66% think that land owners are making a lot of money due to fracking, 20% do not.
Muhlenberg College Institute of Public Opinion, University of Michigan Ford School of Public Policy	Oct-Nov 2011	PA	525	33% strongly agree that fracking poses a major risk to water resources, 27% somewhat agree, 13% somewhat disagree, 15% strongly disagree, 12% not sure	
The University Texas at Austin - Energy Institute	2011	Barnett Shale Area (TX)	1,500	35% are very concerned about water quality, 40% are somewhat concerned, 24% were not very concerned or not at all concerned	generally positive attitude toward fracking: good for the economy, important for US energy security useful, important, effective, valuable, and productive

Table 4: Public trust in stakeholders and opinion on "fracking"-related regulation[(9), (61), (62)]

Sponsor	Dates	Location	Sample Size	Trust	Regulation
The University of Texas at Austin – Energy Poll	Sep 2013	USA	861	39% scientific community, 19% env organizations, 10% the EPA or other federal agencies, 7% oil and gas companies or associations, 6% colleges and universities, 5% state regulatory agencies, 4% local government, 3% the President, 1% the Congress, 6% other	43% should be more regulation, 22% existing regulation is sufficient but needs better enforcement, 14% already too much regulation, 10% existing regulation and enforcement are sufficient, 10% don't know
The University of Texas at Austin – Energy Poll	Mar 2013	USA	889	40% scientific community, 14% env organizations, 12% the EPA or other federal agencies, 11% oil and gas companies or associations, 6% colleges and universities, 2% state regulatory agencies, 2% local government, 2% the President, 0% the Congress, 8% other	43% should be more regulation, 23% existing regulation is sufficient but needs better enforcement, 14% already too much regulation, 13% existing regulation and enforcement are sufficient, 7% don't know
The University of Texas at Austin – Energy Poll	Sep 2012	USA	726	40% scientific community, 12% env organizations, 11% the EPA or other federal agencies, 10% oil and gas companies or associations, 8% colleges and universities, 7% state regulatory agencies, 3% local government, 1% the President, 1% the Congress, 7% other	39% should be more regulation, 23% existing regulation is sufficient but needs better enforcement, 15% already too much regulation, 11% existing regulation and enforcement are sufficient, 12% don't know
The University of Texas at Austin – Energy Poll	Mar 2012	USA	752		38% should be more regulation, 22% existing regulation is sufficient but needs better enforcement, 14% already too much regulation, 16% existing regulation and enforcement are sufficient, 10% don't know
CBS News/New York Times Poll	Mar 2011	USA	1,382		5% there is too much federal regulation, 14% not enough, 10% about right, 5% don't know
Deloitte	Nov 2011	USA, mature shale plays, newer shale plays	1,730	general population: 663	
				17% consider media extremely/very trustworthy, 44% somewhat trustworthy, 28% not very trustworthy, 11% not at all trustworthy not very trustworthy	21% too much regulation, 19% just right, 35% evolving, but on the right track, 16% too little, 10% not sure
				mature shale plays: 573	
				18% consider media extremely/very trustworthy, 41% somewhat, 27% not very, 11% not at all trustworthy	30% too much regulation, 12% just right, 30% evolving, but on the right track, 19% too little, 9% not sure

				newer shale plays: 494	
				17% consider media extremely/very trustworthy, 51% somewhat, 23% not very, 9% not at all trustworthy	18% too much regulation, 18% just right, 40% evolving, but on the right track, 17% too little, 7% not sure
United Technologies/ National Journal Congressional Connection Poll	May 2012	USA	1,004		15% ban fracking, 53% more regulation but no ban, 25% less regulation, 7% unsure
Bloomberg	Dec 2012	USA	1,000		66% more regulation, 18% less regulation, 16% not sure
Bloomberg	Sep 2012	USA	1,007		56% more regulation, 29% less regulation, 15% not sure
Bloomberg	Mar 2012	USA	1,002		65% more regulation, 18% less regulation, 17% not sure
Public Policy Institute of California (PPIC)	Sep 2013	CA	1,703		56% favor stricter regulation, 30% oppose, 13% don't know
University of Michigan & Muhlenberg College	May 2013	MI, PA	839	MI	
				28% Env groups, 20% state gov, 10% local gov, 9% drilling industry groups, 8% TV, 6% federal gov, 5% newspapers, 5% none of the options, 7% other options, 2% not sure	stricter regulation should be avoided: 19% strongly agree, 23% somewhat agree, 18% somewhat disagree, 33% strongly disagree, 8% not sure
				PA	
				33% env groups , 12% state gov, 9% TV, 7% local gov, 7% drilling industry groups, 5% federal gov, 5% newspapers, 6% none of the options, 9% other option, 8% not sure	stricter regulation should be avoided: 22% strongly agree, 19% somewhat agree, 20% somewhat disagree, 28% strongly disagree, 10% not sure
Cornell University Survey Research Institute	2012	NYS	800		local government should be able to control natural gas development in their jurisdiction: 61% agree/ strongly agree, 10% neither agree nor disagree, 28% disagree/ strongly disagree
Mercyhurst University - The Mercyhurst Center for Applied Politics	Sep -Oct 2013	PA	579		63% think that more regulation is needed in PA, 20% less, 3% depends, 15% don't know
Mercyhurst University - The Mercyhurst Center for Applied Politics	Sep -Oct 2011	PA	298		67% think that more regulation is needed in PA, 19% less, 3% depends, 10% don't know
The University Texas at Austin - Energy Institute	2011	Barnett Shale Area (TX)	1,500		disclosure of chemicals used in fracking: 12% thought that the officials are doing everything they should, 32% some of what they should, 47% not as much as they should, 9% nothing at all

*References for surveys to be compiled in the final version

APPENDIX B

Summary of the changes in the regulatory actions in the eight states (TX, PA, MI, IL, OH, CO, CA, NY) where UGD is taking place or being considered

Texas

In Texas, Texas Railroad Commission of Texas (RRC) is the entity responsible for permitting and regulating oil and gas production in state. It is the oldest government agency in the state and one of the oldest such regulatory bodies in the nation. Texas has a very robust and old oil and gas industry. UGD was developed in the state and has the most mature history of the practices.

The Commission has taken the position that UGD is not fundamentally different from conventional gas development and thus the same permitting procedures are applicable to UGD.

In March 2011, House Bill 3328 was passed by the Texas state legislature (Republican majorities in the Senate and in the House of Representatives) and was signed into law by Governor Rick Perry (Republican). The bill requires the disclosure of all chemicals used in the hydraulic fracturing process as well as the amount of water used in the fracturing process. The regulations do not require that the concentrations of the chemicals be disclosed. The chemical disclosure requirement can be challenged by industry with the “trade secret status exemption,” which in turn could be challenged by the Public Information Act. Under previous regulation a list of chemicals used was to be provided at each site as required by federal Occupational Health and Safety Administration (OSHA).

Michigan

In Michigan, the Office of Oil Gas and Minerals (OOGM) within the Department of Environmental Quality (DEQ), is the entity responsible for permitting and regulating oil and gas production in state. Michigan has a well-established oil and gas industry and has a history of UGD and associated practices.

Hydraulic fracturing is regulated under the Natural Resources and Environmental Protection Act, Act No. 451 of the Public Acts of 1994, as amended (last amended 9/10/2004) that regulates oil and gas operations. The specifics of fracking permitting procedure were clarified in the Supervisor of Wells Instruction of 2011. It contains reporting requirements with regard to large volume water withdrawal, freshwater monitoring and reporting requirements, i.e. with regard to the Material Safety Data Sheets provided by the service company for the chemical used and their volumes.

In October 2013 the Department of Environmental Quality announced that it is working on new rules for regulating fracking. Permit applications for fracking activities are to be updated to include water withdrawal assessments based on the state’s water withdrawal assessment tool, water monitoring, water quality sampling, monitoring and reporting of fluid pressures and volumes for all high volume fracturing operations, as well as a submission of information on chemical additives used are to be submitted to the internet-based FracFocus Chemical Disclosure Registry.

Ohio

In Ohio, the Division of Mineral Resources Management, within the Ohio Department of Natural Resources (ODNR) is the entity responsible for permitting and regulating oil and gas production in state. Ohio has a history of oil and gas production with a well-established industry. UGD has been and continues to be a significant element of the development.

In 2004, HB 278 became law, recognizing the ODNR as "the sole and exclusive authority to regulate the permitting, locating and spacing of oil and gas wells" and thus eliminating local "home rule" for city governments to regulate those aspects of oil and gas drilling. Under former law, the authority for issuing oil and gas exploration permits was shared between state and local levels of authority. The exclusive administrative authority of ODNR has been challenged over the last few years.

In April 2011 the city of Munroe Falls took Beck Energy Corp to court, halting their drilling operations. Beck Energy Corp had not obtained local zoning permits and drilling permits, did not pay an application fee, and disregarded city ordinances regarding truck traffic, though Beck did have a drilling permit issued by the state ODNR. Ohio Supreme Court agreed in June 2013 to hear the case, which could set an important precedent in the state regarding "home rule" and whether cities or the state have the ultimate authority over regulating the oil and gas industry.
In November 2013 there was a number of failed attempts to ban fracking in Ohio's cities (Bowling Green, Youngstown). A ban was passed 71% to 39% in Oberlin, a small, liberal college town where no drilling is actually taking place, according to the Ohio Oil and Gas Association (OOGA).

Colorado

In Colorado, the Colorado Oil and Gas Conservation Commission (COGCC), within the Department of Natural Resources is the entity responsible for permitting and regulating oil and gas production in state. Colorado has a significant history of oil and gas production and a mature industry. UGD has been a key component of the development.

In 2008, a comprehensive overhaul of oil and gas regulations began in Colorado. New rules addressed land reclamation, initial site preparation, setbacks from surface water, stricter wastewater pit requirements, and spill notification requirements. The Colorado Oil and Gas Conservation Commission (COGCC) approved the new rules by an 8-0 vote in December, 2008. Another series of regulations were passed in 2012. These included setbacks from buildings, increased noise abatement, dust regulations, mandatory public comment period extensions, drilling notification for nearby residents, groundwater sampling and monitoring, and chemical disclosure requirements. Additional rules and regulations pertinent to hydraulic fracturing have continued to be developed and issued from 2008 and 2012. These include: Rule 205: Inventory chemicals used in hydraulic fracturing, Rule 205A: Chemical disclosure requirements, Rule 305.e.A: Landowner Notice of Intent to Hydraulic Fracture, Rule 317: Well casing and cementing standards, Rule 317B: Setbacks and precautions near surface waters and tributaries that are sources of public drinking water, Rule 341: Monitoring pressures during stimulation, Rule 608: Special requirements for coal-bed methane wells, Rule 609: Baseline sampling of groundwater before drilling and monitoring, for at least five years within a half-mile radius of all new oil and gas wells
Rules 903 & 904: Pit permitting, lining, monitoring, & secondary containment, Rule 906: Requires COGCC to notify the Colorado Department of Public Health and the landowner of any spill that threatens to impact any water of the state.

Home rule for municipalities in Colorado is allowed through an article of the Colorado Constitution. Municipalities are granted "functional home rule", meaning citizens have the right to decide the structure as well as the powers and functions of the municipality. Whether this applies to regulation of oil and gas drilling has is hotly contested after several cities have now exceeded state-level regulation.

In November 2012 the city of Longmont passed ban on fracking 60% to 40%. The city is being sued by COGA and the Governor Hickenlooper administration. In November 2013, multiple cities - Fort Collins, Boulder, Lafayette, Broomfield - passed moratoria on fracking.

California

In California, the Division of Oil, Gas, and Geothermal Resources (DOGGR), within Department of Conservation is the entity responsible for permitting and regulating oil and gas production in state. California has a well-established and substantial oil and gas industry based on the production from conventional reservoirs. UGD has yet to be established there.

September 2013, California passed Senate Bill 4 (SB4), which under emergency rulemaking process established one of the most comprehensive set of regulations on “well stimulation” activities in the United States. Previous law regulated oil and gas development without having specific provisions on fracking. SB4 establishes an interim regulation of fracking that went into effect on January 1, 2014. Permanent regulation is anticipated to become effective on Jan 1, 2015.

Key piece of the permanent regulation is a rigorous permitting procedure. Under SB 4 the regulation of fracking falls into authority of the DOGGR to issue permits.

During the interim period, the operators are not required to obtain a permit. However, SB4 introduces requirements that the operators need to comply with from Jan 1, 2914 on. Those requirements include public disclosure of information on chemicals used and their concentrations, a notification of landowners and tenants within a specified distance (‘neighbor notification”), groundwater monitoring and water management plans. If a company claims to withhold the information on chemicals from the public disclosure on the grounds of the trade secret protection, it still needs to provide this information to governmental entities. Public has the right to challenge the trade secret claim at the court.

Furthermore, under SB 4 governmental entities are required to prepare an environmental impact report, an independent scientific study on well stimulation treatments, and the groundwater modeling criteria.

New York

In New York, Department of Environmental Conservation (DEC) is the entity responsible for permitting and regulating oil and gas production in state. New York is the oldest oil and gas producing state in the Union and had a robust industry in the past. UGD was established in the state in the recent past on a small scale.

In 1992, the Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program (GEIS) was prepared to review the Department of Environmental Conservation's program for regulating oil, gas, underground gas storage and solution mining wells of any depth, and brine disposal, stratigraphic and geothermal wells deeper than 500 feet. The GEIS was prepared according to the State's Environmental Quality Review Act (SEQRA). During 2008 there was an increased interest in the issuance of permits for horizontal drilling and high-volume hydraulic fracturing to develop the Marcellus Shale and other low-permeability gas reservoirs. In response, Governor Cuomo determined that UGD is distinct from conventional gas development, a uniqueness determination that triggered a requirement for the development of a Supplemental Generic Environmental Impact Statement (SGEIS) under the

New York State Environmental Quality Review Act of 1977. At the urging of environmental groups, the New York legislature passed a one-year moratorium on UGD in 2010, but the moratorium was vetoed by the Governor. To address the concerns, the Governor instead issued an executive order prohibiting hydraulic fracturing of horizontal wells until July 1, 2011. In other words, no permits for UGD were permitted to be issued in New York until the scheduled completion of the final supplemental environmental impact statement.

In July 2011 the new Governor of New York released a draft plan to prohibit UGD in many regions of the state but leave open for drilling about 85% of the State's Marcellus Shale, including the region along the border with Pennsylvania. After widespread criticism of this plan, the Governor proposed an alternative plan in 2012 that would limit UGD to the economically depressed counties near the Pennsylvania border called the Southern Tier. Specifically, UGD would be permitted in these small towns only if the town consented to UGD by popular vote. This form of "local option" was controversial because some legal experts believed that local towns lacked the authority under the state's constitution to restrict UGD. Ultimately, the Supreme Court Appellate Division of the State of New York upheld a decision that local governments are allowed to use their zoning power to prohibit UGD in within their borders.

The local-option plan spurred a town-by-town political battle between proponents and opponents of UGD. Although numerous communities in upstate New York voted to prohibit UGD, about sixty communities, most of them in the five-county region that might be free to undertake UGD under the Governor's plan, indicated that they would permit UGD in accordance with state regulations. The political contest in New York's Ostego County was quite intense, and opponents appeared to gain an upper hand over time. The number of Ostego towns with bans or moratoriums on UGD increased from five to nine from mid-2011 to early 2013.[i]

In March of 2013 the New York State Assembly, which has a Democratic majority, passed a two-year moratorium that suspends UGD until May 15, 2015, thereby allowing more time for completion of additional health and environmental studies. The Governor of New York has indicated that he will make a decision on UGD for the State when the Commissioner of Health completes his review. No deadline has been set. The issue is politically sensitive because the Governor is up for re-election in November 2014 and because the governor is seen as a possible Democratic presidential candidate in 2016.

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