Natural Gas Extraction Using Hydraulic Fracturing: Creating a Sustainable Path Forward

Panko, J.M., A. Foda, S.A. Gross, K.M. Hitchcock, J.N. Kennedy, P.K. Scott, B.E. Tvermoes, K.M. Unice

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For More Information

Julie M. Panko
Principal Health Scientist
20 Stanwix Street
Suite 505
Pittsburgh, PA 15222
(412) 281-6900 (Ext 1020)
jpanko@chemrisk.com

Introduction

Global demand for energy is estimated to grow by 70 percent by 2050. Most of this demand will be satisfied by non-renewable fossil fuels such as natural gas and oil as the world slowly transitions to alternative sources of energy.

Meanwhile, we must make the most of the resources we have, and extract them as efficiently and responsibly as possible. This is driving advances in various extraction technologies, including hydraulic fracturing (HF) to recover natural gas.

HF is the injection of fluids formulated to physically fracture subsurface bedrock for the purpose of oil and gas recovery. Although the method has received recent attention in states like Colorado, Texas, and Pennsylvania, the technology is mature and has been in commercial use since the 1940s.

The renewed interest in HF is a result of recent technological advances, including well design and horizontal boring. These technologies make the recovery of oil and gas resources economically feasible in areas where this was not possible previously.

The latest activity has also introduced gas recovery operations to suburban and urban populations unaccustomed to negotiating and communicating with the petroleum industry. While some people see economic gains and energy independence, others are concerned about damage to private property and natural habitats, drinking water contamination, adverse health impacts, and more.

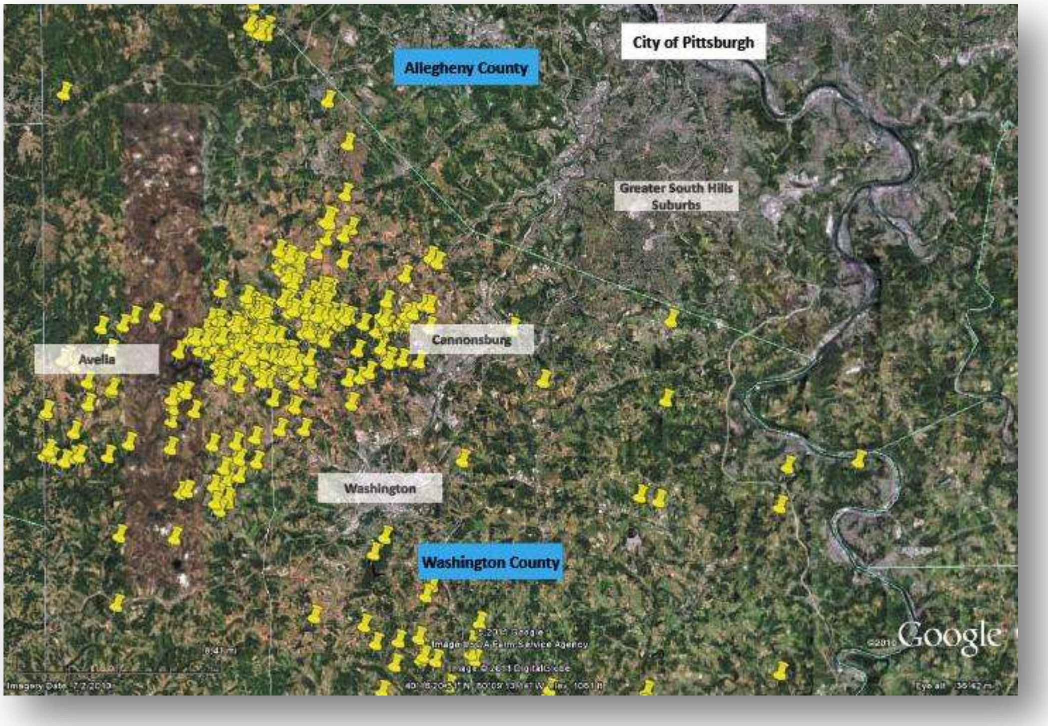
Today, various stakeholders, including the oil and gas industry, academic institutions, governmental agencies, environmental advocacy groups, and community leaders are seeking to understand the various dimensions of gas recovery in a manner that is consistent with their sustainability mission and goals.

As with most questions, it is difficult to identify, evaluate, or resolve legitimate concerns without a proper framework, and one of the unique aspects of HF is the lack of a unified evaluation framework to assess different types of hazards and data gaps. For example:

- In the Marcellus Shale, there is concern about the hazard of explosion associated with the occurrence of methane in drinking water wells near gas extraction sites. However, there is little data available regarding the importance and mitigation of the potential pathways including fracture transport, stimulation of near-surface bacterial methane generation, or preferential transport near the sidewall of the completed well.
- Reviews of HF fluids commonly list additives for at least 10 different properties, but few reports have attempted to characterize the relative level of concern about these additives during mixing or spills, or remaining in the 30 to 70% of fluids recovered after injection of the fluid.
- Increased volume of truck traffic associated with well development impacts local road infrastructure and increases exhaust emissions to residents of suburban and urban communities
- Although it is estimated that less than 1% of the water use in a basin will be directed to HF uses, very little is known about how the short-term demands for massive quantities of water affect public water supplies, recreational uses and aquatic habitats.

The Risk Assessment Paradigm is the accepted scientific framework for conducting an unbiased and comprehensive evaluation of the likelihood of an adverse human or ecological health outcome. Established by the National Academies of Science in 1983 and reaffirmed in 2009, this framework consists of hazard identification; determining the relationship of exposure to the hazard and adverse response; the frequency, magnitude, and duration of exposure; and finally determining the likelihood of an adverse outcome (NRC 1983). Following the characterization of risk, decisions about risk management are made taking into account control measures, regulatory requirements, economic factors and social considerations.

In this white paper, ChemRisk proposes the development of a consensus conceptual exposure model and generic risk assessment for HF such that real risks can be understood and eliminated or minimized, data gaps/needs can be prioritized for future research, and risks can be communicated more accurately and effectively.



Locations of existing or future gas operations in Western PA relative to population centers (July 2010)

THE GEOLOGY AND GEOGRAPHY OF HYDRAULIC FRACTURING

Exploration and recovery of natural gas in low porosity underground formations is growing rapidly with recent advances in HF technology; thousands of wells are being drilled in various geographical regions across the United States (U.S.). The geology (e.g. sandstone and carbonate, coal beds, shale formations) of each geographical region dictates the type of procedures used for extraction of the natural gas. See Figure 1.

Coal beds consist of coal seams containing thermogenic and biogenic natural gas. Thermogenic natural gas is derived from the thermal transformation of coal, whereas biogenic natural gas is generated from the microbes that are native to the coal beds. Coal beds are often also sources of groundwater used for drinking water. Although horizontal drilling and hydraulic fracturing are used to create some of the coal bed wells, these wells are drilled shallow because the coal beds are too fragile to withstand a substantial increase in porosity under pressure. When hydraulic fracturing is used in these shallow formations, it is subject to local and state regulatory restrictions to protect drinking water sources (DOE 2009).

Access to natural gas can also be achieved by exploring low permeability shale formations using hydraulic fracturing in combination with vertical and horizontal wells. Natural gas is created from the organic matter indigenous to the shale and can be found in both large and small pores within the structure of the shale. As of 2009, at least 25 shale gas formations were identified across the U.S., including a large portion of the states of Illinois, Indiana, Michigan, Ohio, West Virginia, New York and Pennsylvania.

Natural gas found in low porosity sandstone and carbonate reservoirs is accessed primarily by horizontal drilling and hydraulic fracturing because the natural gas is lodged tightly within these formations. Many of these reservoirs are formed over time by the migration of natural gas into the reservoir from outside of the reservoir. These reservoirs are located anywhere from 1,200 to 20,000 feet in depth and are referred to as “tight” gas (USEPA 2011a). As with coal beds and shale formations, tight gas reservoirs are scattered across the U.S. with the largest sand reservoirs located in the Appalachian basin in the upper portion of eastern U.S.; the Austin Chalk, which spans across parts of Texas, Louisiana, and Mississippi; and the Denver basin, located in Colorado, Wyoming, and Nebraska (EIA 2009).

Pennsylvania, Ohio, and West Virginia are overlaid with the Northern Appalachian coal beds, the Marcellus Shale formation, and the sandstone and carbonate of the Appalachian basin, thus creating a “hotbed” for natural gas exploration and recovery. Colorado and Texas, on the other hand, have minimal overlay in hotspots of natural gas from such geological formations. Differences in each of the ‘unconventional’ gas sources give rise to somewhat different environmental concerns.

About the Authors

Julie M. Panko is a Principal Health Scientist at ChemRisk, LLC, where she specializes in human health risk assessment and product sustainability; she holds a B.S. in Industrial Hygiene from the Ohio University. Her most recent publication was on acute aquatic toxicity of tire and road wear particles; it appeared online this year in Ecotoxicology July 26, 2011. doi: 10.1007/s10646-011-0750-x.

Amina Foda is an Assistant Health Scientist at ChemRisk, LLC, where she specializes in reviewing and analyzing water data; she holds a B.S. in Psychology with an emphasis on biology from the University of California, Davis.

Sherilyn A. Gross is a Senior Health Scientist at ChemRisk, LLC, where she specializes in conducting studies evaluating human health risks following exposure to benzene; she holds a Ph.D. in Toxicology from the University of Colorado and a B.S. from the University of Denver. Her most recent publication was on modeling airborne concentrations; it appeared online this year at Environmental Science & Technology July 28, 2011. doi: 10.1021/es200963x.

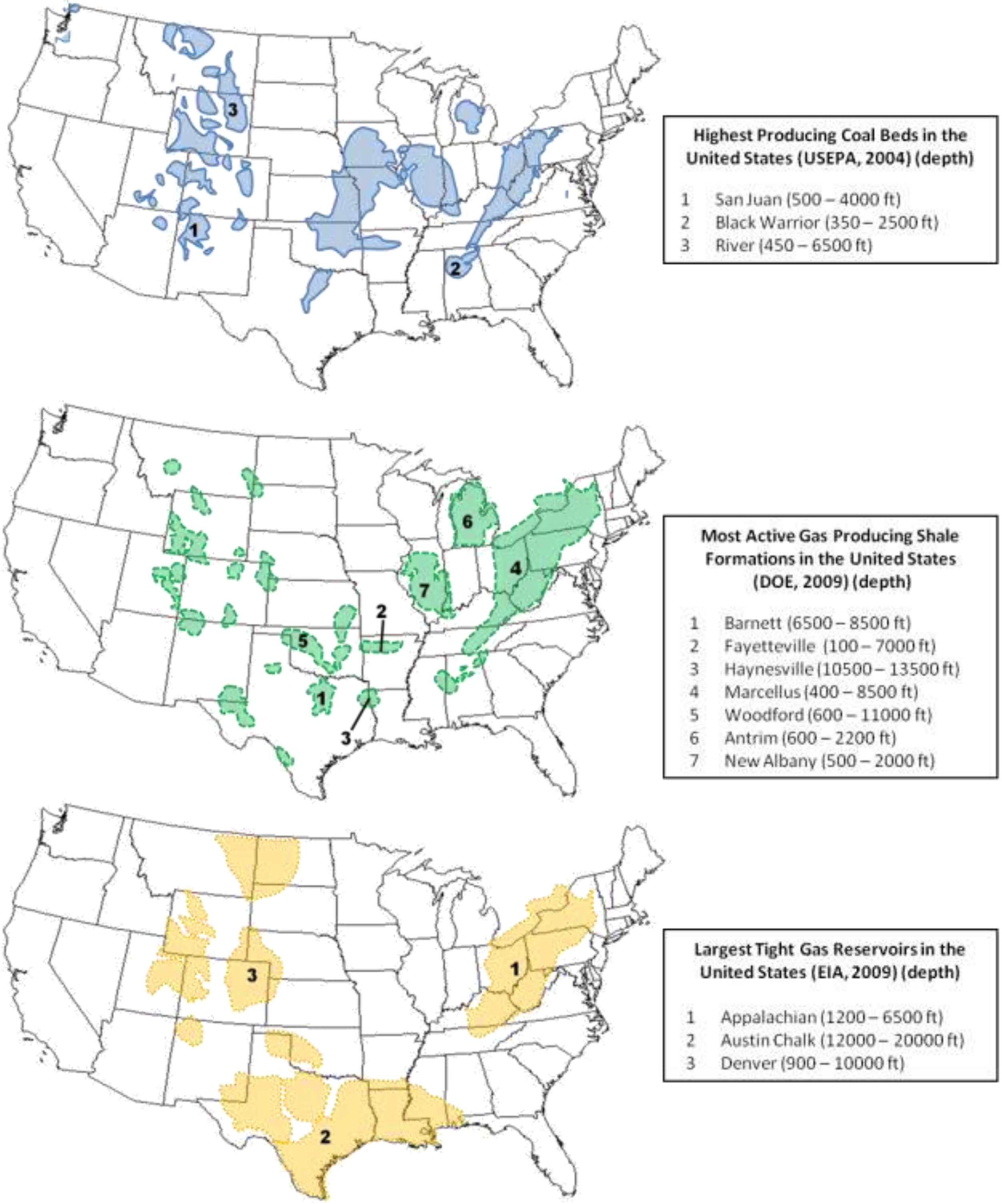
Kristen M. Hitchcock is an Associate Health Scientist at ChemRisk, LLC, where she specializes in exposure risk assessment, environmental and occupational health, water quality, and life cycle analysis; she holds a M.E.M. in Environmental Health and Security from Duke University and a B.S. in Applied Biology from Georgia Institute of Technology.

Jason N. Kennedy is a Health Scientist at ChemRisk, LLC, where he specializes in biomedical engineering and environmental and occupational health; he holds a Ph.D. in Biomedical Engineering from Saint Louis University and a B.S. in Biomedical Engineering from the Washington University.

Paul K. Scott, Q.E.P., is a Supervising Health Scientist at ChemRisk, LLC, where he specializes in applied statistics, exposure assessment methods, and fate and transport modeling in the areas of environmental forensics, epidemiology, toxicology, occupational health, and human health and ecological risk assessment; he holds a B.S. in Mathematics from Southwest Missouri State University. His most recent publication was on dioxin toxicity; it appeared this year in Environmental Health Perspectives (119(5):713-718).

Brooke E. Tvermoes is an Health Scientist at ChemRisk, LLC, where she specializes in metals toxicology; she holds a Ph.D. in Molecular Toxicology from Duke University and a B.S. in Chemistry from Northern Arizona University.

Ken M. Unice is a Supervising Health Scientist at ChemRisk, LLC, where he specializes in computer programming, database and quantitative human health risk and exposure assessment; he holds an M.S. in Chemical and Environmental Engineering from the University of Arizona and a B.S. in Civil Engineering from Cornell University. His most recent publication was on modeling airborne concentrations; it appeared online this year at Environmental Science & Technology July 28, 2011. doi: 10.1021/es200963x.



Highest Producing Coal Beds in the United States (USEPA, 2004) (depth)

1 San Juan (500 – 4000 ft)
2 Black Warrior (350 – 2500 ft)
3 River (450 – 6500 ft)

Most Active Gas Producing Shale Formations in the United States (DOE, 2009) (depth)

1 Barnett (6500 – 8500 ft)
2 Fayetteville (100 – 7000 ft)
3 Haynesville (10500 – 13500 ft)
4 Marcellus (400 – 8500 ft)
5 Woodford (600 – 11000 ft)
6 Antrim (600 – 2200 ft)
7 New Albany (500 – 2000 ft)

Largest Tight Gas Reservoirs in the United States (EIA, 2009) (depth)

1 Appalachian (1200 – 6500 ft)
2 Austin Chalk (12000 – 20000 ft)
3 Denver (900 – 10000 ft)

Figure 1. Major U.S. Coal Basins, Shale Formations and Tight Sand Basins

(EPA, 2004; U.S. Dept Energy, 2009; EIA, 2009)

BASICS ABOUT DRILLING, FRACTURING FLUID, AND FLUID RECOVERY & STORAGE

The fracturing process is initiated by drilling a production well down to the target rock formation. Several layers of steel casings, reinforced with cement seal along the length, are then installed to line the well (NRC 2010). This barrier is critical for efficiently retrieving released gases and produced water, as well as for protecting surrounding formations and groundwater aquifers. The integrity of the casing must be monitored to prevent possible leaks in the casings that could contaminate surrounding water sources. Standards for casing and cement application are set by state regulations, thus the process and casing specifications differ between wells and locations.

Chemically enhanced water, referred to as fracturing fluid, is injected into the well at significant rates and sufficient pressure. As the pressure builds up in the well and resistance in the rock formation can no longer withstand the pressure, existing fractures extend and new ones are created, wherein the fracturing fluid, consisting of sand, gels, and chemicals, migrates. The resulting fractures facilitate a network of connections between the fractures and the well cavity, the ultimate destination of the released gas and injected water (USEPA 2004).

Exact compositions of fracturing fluids are difficult to obtain because of chemical variability between fracture sites and manufacturers, and because the formulations are considered to be proprietary (USEPA 2004; Wilson 2010). However, approximately 99.51% of the fluid is typically water and sand while the remaining 0.49% consists of a variety of additives that serve various purposes (DOE 2010). Among these additives, chemicals such as glycol ethers, acids, caustics, petroleum distillates, aromatic hydrocarbons, and many other compounds are used to achieve a certain viscosity and slickness, inhibit corrosion of the well casing, prevent bacterial growth in the well, and enable delivery of proppants to fracturing sites. Once the fluid is delivered to the fractures, the sand in the fluid serves as a proppant to maintain the fractures from closing (USEPA 2004). A submersible pump installed at the bottom of the well cavity then pumps the fluid back, releasing the hydrostatic pressure and allowing the adsorbed gas to escape and flow up to the surface of the well (Ganjegunte et al. 2005; NRC 2010).

The flowback of the fracturing fluid is diluted by produced water from the fracture, making it difficult to accurately monitor the fraction of fracturing fluid recovered (NRC 2010). In the event that retrieval of fracturing fluid is not guaranteed, concern of groundwater contamination by produced water becomes a critical element for regulation (NRDC 2002; USEPA 2004). Presently, the recovered water is stored and disposed of in a variety of ways including: underground injection, direct discharge to surface water, and transfer to storage ponds, where the water is stored for further use. Management of the recovered water is dependent on various factors, including: 1) water quality and quantity, 2) degree of compatibility between produced water and potential receiving landscapes, land parcels or water bodies, 3) proximity of produced water to locations suitable for beneficial use, and 4) availability of storage and disposal sites (DOE 2009; NRC 2010).

Water-related concerns vary by well depth, geography, and type of well.

- Fracturing of deeper wells typically requires greater volumes of water than shallower wells, and significantly more water is required for the hydraulic fracturing of shale than for sandstone.
- The depth and type of rock formations have substantial implications for risk to the drinking water aquifer. For example, shale formations are found on average at much greater depths than other well types, which often places them further away from the drinking water aquifer. Shallower wells can lie much closer to the aquifer, leading to higher risk of contamination.
- Coal bed methane extraction carries different risks from both sandstone and shale. In these wells, water is removed from underground coal beds to promote desorption of methane from a solid coal matrix. The water produced during this process must then be handled appropriately to ensure safe release into the environment.

HYDRAULIC FRACTURING AND ENVIRONMENTAL CONCERNS

The rapid expansion in the number of wells being drilled, the location of wells on private property, and the proximity of the wells and ancillary gas production facilities to suburban/residential areas and schools have led to a high level of concern about the potential human health and environmental impacts of hydraulic fracturing. Additionally, news reports of explosions, contaminated drinking water, and regulatory exclusions for the industry have resulted in public outrage and backlash against the industry and municipal, state, and federal governments. The major concerns expressed are:

- Potential surface and ground-water contamination
- Air emissions of volatile organic compounds (VOCs) could result from all phases of well development and production.
- Management and disposal of fracturing fluid waste
- Negative impacts on local wildlife
- Hazards associated with the transportation of fracturing fluids
- Withdrawal of large volumes of water from nearby ground and surface waters

Although many natural gas and oil wells are completed in targeted formations located thousands of feet below drinking water sources, these wells are often drilled through drinking water aquifers located above the gas-bearing formations. Thus, if any part of the well casing is compromised, fracturing fluids may leak from the wellbore and adversely impact nearby water sources (Mueller 2011; USEPA 2011a). The management and disposal of the recovered water is another concern. The recovered water contains constituents from the original fracturing fluids as well as natural pollutants released from the targeted oil or gas formation, e.g. metals and radionuclides (USEPA 2011a). Since this water is generally stored on site in holding ponds or tanks before being transported for treatment or disposal, the accidental release of fracturing fluids from holding ponds may occur if the ponds are not properly lined or if the lining tears, which could result in soil and groundwater contamination (NYDEC 2009; USEPA 2011a).

In addition, not all fracturing chemicals are fully recovered after being injected into the ground. These chemical constituents may continue to migrate and adversely impact underground water resources (Mueller 2011). Concerns have also been raised about the potential for fractures to extend beyond the target formation (Mueller 2011; NYDEC 2009; Osborn et al. 2011). This could open up preferential pathways allowing fracturing fluids and natural gases (e.g., methane) to migrate outside the shale formation and potentially reach drinking water aquifers located several thousand feet above (NYDEC 2009; Osborn et al. 2011).

Air quality may also be affected by the extraction of natural gas through hydraulic fracturing. Volatile organic compounds (VOCs) can be released into the air at all stages of gas operations including exploration, drilling, and the processing of gas to separate methane from fluids and other gases (ATSDR 2008; NYDEC 2009). Off-gassing of the well before it is operational constitutes a major potential source of VOC emissions (NYDEC 2009). In addition, VOCs may be released from recovered water that is placed in open holding ponds for evaporation (ATSDR 2008). While the main concern for VOCs outdoors is the production of ozone, which is a constituent of photochemical smog, adverse health effects are associated with these compounds as well (ATSDR 2008; USEPA 2011b).

PAST, PRESENT AND FUTURE

The oil and gas industry has long been aware of the potential for environmental impacts of their operations and have made great strides over the last 50 years to develop techniques to minimize environmental risks. From tens of millions of dollars spent to remediate the local impacts associated with the thousands of manufactured gas plants of the late 19th and early 20th century to the assessment of widespread impacts from pipeline operations and clean-up of off-shore oil spills, the industry has a rich history upon which to reflect and plan for the future. While history tells us that there can be no progress without some risk, most environmental risks are predictable and therefore can be managed to ensure people and the environment are protected.

Recent votes by shareholders of major oil companies indicate the desire of investors to understand both the environmental and financial risks associated with the hydraulic fracturing activities of the companies in which they have invested. This alignment of shareholder values and stakeholder values is due in part to increased expectations of transparency and increased expectations that companies deliver their products in a sustainable, environmentally friendly way.

Drilling for natural gas, a finite energy source, does not neatly fit the definition of sustainable development; however, it can be extracted in a responsible manner that can in turn be reported to the public to alleviate anxieties. The three largest oil and gas industry associations have published voluntary industry guidance on sustainability reporting (IPIECA/API/OGP 2010). This guidance provides a means for reporting to both shareholder and stakeholder the efforts to minimize the environmental impact of hydraulic fracturing and extraction portion of the natural gas life cycle.

However, that will not be enough. To address HF-related environmental and health concerns, a unified evaluation framework needs to be adopted by the oil and gas industry. In the U.S., the Risk Assessment Paradigm continues to be recommended as the appropriate and scientifically defensible framework to protect human health and the environment (NRC 2009). ChemRisk supports this approach and recommends risk assessment as the basis for evaluating environmental concerns associated with HF operations and gas production.

ChemRisk believes that a simplified conceptual model emphasizing chemical risk, such as that shown in Figure 2, could be adopted as a starting point. The model shows the manner in which chemical exposures could occur following releases from fluids used in well development and fracturing as well as from gases, salts, and metals originating from the formation itself. The potential exists for impacts to all environmental compartments, including air, water, soil and sediment. The magnitude and relative importance of these impacts depends on the mobility, toxicity, persistence, and bioavailability of each individual chemical of concern. Strategies for risk management are also evident from the conceptual model, such as recycling of fracture water to reduce local demand for fresh water, ambient air monitoring and controls to address fugitive emissions, and early detection systems for monitoring failures in well integrity.

> *Sustainability… satisfying the needs of the current generation without sacrificing the ability of future generations to do the same and embracing the triple bottom line "balance" of environmental, social and economic progress.*

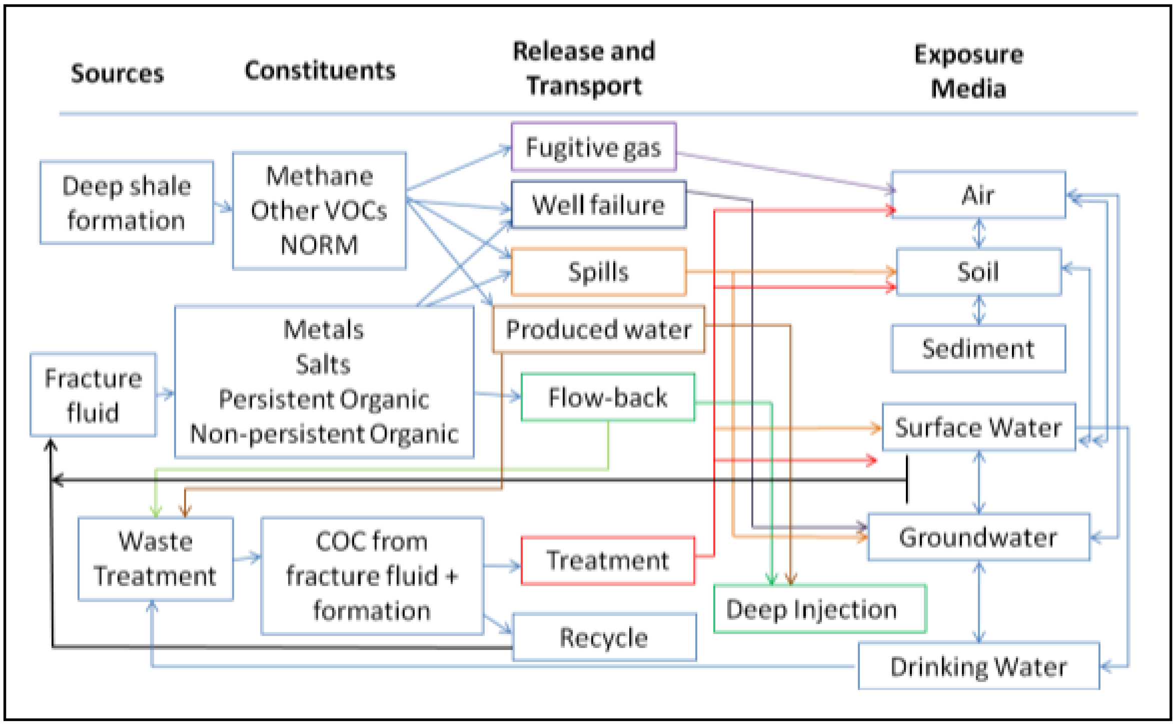


Figure 2. ChemRisk Proposed Conceptual Exposure Model for Use in HF Risk Assessment

SUMMARY

Currently, natural gas production is essential to U.S. energy security and economic progress. Advanced hydraulic fracturing will enable the U.S. to extract it from the country's vast reserves. However, all stakeholders (and increasingly shareholders) want to be assured that the potential environmental impacts associated with HF technology have been properly assessed, risks have been characterized and controls are in place to protect people and the environment.

A unified evaluation framework, based on the accepted Risk Assessment Paradigm and the simplified conceptual exposure model, will help answer those questions and drive sustainable solutions for the future.

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