Unconventional Oil and Natural Gas Resources Development and Their Potential Environmental Impacts

A look at the potential impacts hydraulic fracturing operations can have on the environment, as well as a short assessment of various policy instruments and technological innovations to help manage the additional risks posed by increased unconventional oil and gas explorations.
The estimated oil reserves from tight oil (shale) plays have dramatically increased over the past few years and the potential recoverable oil from tight oil plays is currently estimated to be 7,338 million barrels.\(^1\) The U.S. crude oil field production increased from roughly 5 million barrels/day in 2008 to more than 7.4 million barrels/day in 2013.\(^2\) During the same period, U.S. oil imports dropped significantly from 13 million barrels/day to 9.8 million barrels/day.\(^1\) In a similar manner, natural gas production increased by 5% in 2012 and 7% in 2011.\(^2\)

The exploration and development of unconventional oil and gas resources has had considerable economic impacts, and employment in oil and gas fields is estimated to have increased by 40% since late 2007.\(^3\) These resources are viewed by many as a way to reduce our reliance on foreign oil imports and secure U.S. energy independence. Unconventional oil and gas resources provide a vital bridge in our transition toward renewable energy sources. While the economic boom brought forth by unconventional oil and gas development has created many positive externalities, such as better physical and communication infrastructure and increased employment opportunities, it has also raised concerns on potential negative impacts to the environment. In response to growing public outcry, several towns and cities across the nation have issued moratoria on hydraulic fracturing operations within their jurisdictions.

Environmental Impacts

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While public debates depicting these polarized viewpoints may help increase awareness of the issue, they seldom help address the fundamental question of when and where hydraulic fracturing may be (un)acceptable. If not managed properly, hydraulic fracturing operations can increase water availability stress, cause habitat fragmentation, result in loss of biodiversity, create sediment erosion and pollutant runoff, as well as affect ambient air quality. However, it is important to recognize that the nature and extent of these risks will depend upon prevailing landscape characteristics and hydro-meteorological conditions, as well as operating practices. Not only are shale plays dissimilar in their geological and petrochemical characteristics, their development can lead to very different environmental impacts. Understanding the geographic, hydrologic, and ecological makeup of these areas provides insight into potential exposure pathways and helps contextualize the regional-scale differences between different shale plays in the United States.

Water Availability

As can be seen from Figure 1, major shale plays, such as Eagle Ford, Bakken, Woodford, Barnett-Woodford, and Avalon Bone Spring (Permian Basin) lie in the water parched semi-arid and arid regions of the United States. The typical water demand is approximately 1,000 gallons per foot of horizontal leg, which results in 3–7 million gallons of water per well. While this water use per well is relatively low compared to irrigation or municipal water usage, the rapid proliferation of fracturing wells is often of public concern that has been accentuated by prolonged droughts of recent years, particularly in the western United States. Surface water sources are sometimes used in the northeastern shale plays. While water availability generally may not be of concern here, the timing of diversions could conflict with the maintenance of environmental flow requirements. Groundwater is often the primary source of water in the western shale plays.

Horizontal wells are often fractured over a span of 1–2 weeks and this is when the water needs are highest. Groundwater production over such short-spans, particularly in areas not used to significant production can result in localized impacts such as the drying up of shallow wells (at least temporarily). There is also significant competition for groundwater in shale plays that underlie urbanized areas (e.g., Barnett shale) or in areas with significant irrigated agriculture (e.g., Denver Basin) and these conflicts come to the fore during periods of extended drought.

Brackish (salt or sea) water supplies are available in all active shale plays and use of this water is increasing, reducing competition for potable water supplies and limiting the impacts of hydraulic fracturing on water availability. In order to fully utilize brackish water supplies, a better understanding of the water quality and aquifer characteristics are needed, as well as advances in additive technologies for controlling fouling (both chemical and...
biological), viscosity, and density of the brackish waters for use as hydraulic fracturing fluids.

**Water Quality**

The primary risk to surface water and groundwater contamination are likely due to accidental spills and improper disposal of produced water, which typically contain a variety of hydrocarbons and high concentration salts. Produced water spills have the potential to kill plant and wildlife and make water unusable for drinking even with treatment. In addition, fracturing technology also depends on undisclosed types and amounts of chemicals whose toxicological characteristics are largely unknown. Colborn et al., have compiled a list of 632 chemicals that are used during oil and gas production operations.

The groundwater contamination risks from accidental spills are likely to be more pronounced in northeastern shale plays where the water table is generally shallow. Casing failures and migration through faults can result in groundwater contamination. The upward migration of chemical-laden brine and methane from deeper oil bearing formations into shallower aquifers has been noted in the Marcellus shale plays. However, arguments against such leakages or at least any link to hydraulic fracturing have also been presented in the literature. Methane contamination of shallow groundwater may be due to natural biological activity.

Design guidelines that promote well construction methods protective of groundwater resources emphasize well integrity have been reiterated by the industry. While the risk of groundwater contamination cannot be ruled out at fracturing sites, adherence to design guidelines and proper geological characterization are vital to minimize risks and increase public confidence in the fracturing process.

Hydraulic fracturing operations result in deforestation and increase the extent of impervious area due to well pad and road construction and as such can increase the amount of runoff to nearby creeks and streams. There is evidence of increased sediment and pollutant loadings in the Marcellus shale plays of Pennsylvania. Horizontal drilling reduces this problem by allowing multiple drilling operations from a single pad.

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Figure 1. Major shale plays in the United States in the context of water availability stress.
Impairment to surface water bodies is of greater concern in shale plays in the northeastern United States where there is a dense network of rivers and perennial creeks (see Figure 2). Barnett, Tuscaloosa, and Bakken plays, which occur in the sub-humid parts of the United States, also contain a reasonably dense network of surface water bodies. The Tuscaloosa basin, in particular, has the highest network density when normalized over the area of the shale play (0.185 mi/sq. mi). In contrast, the risks to surface water bodies are the lowest in Barnett-Woodford (Permian Basin), Heath, and Monterey shale plays.

Air Quality
Unconventional oil and gas production and hydrocarbon processing can result in increased emissions of volatile organic compounds (VOCs), fine, and ultrafine particulates (PM). As shown in Figure 3, several shale plays, particularly in the northeast, California, and Dallas areas, are in non-attainment areas that do not meet the National Ambient Air Quality Standards (NAAQS) for ozone ($O_3$), PM$_{2.5}$, or sulfur dioxide ($SO_2$). Shale plays in the Denver Basin and in Utah underlie PM$_{2.5}$ non-attainment areas. Oil and gas activity in urban areas may also lead to localized concerns for direct exposure to airborne contaminants.

In addition, the release of methane from gas production wells can significantly offset the carbon benefits of natural gas as methane is a potent greenhouse gas. Based on measurements from 190 natural gas sites, Allen et al. report that well completion emissions of methane are lower than what was previously estimated. However, emissions from pneumatic controllers and equipment leaks are higher than U.S. Environmental Protection Agency (EPA) projections. Litovitz et al. estimate that the nitrogen oxides ($NO_x$) emissions from all shale gas activities in the Marcellus shale plays in Pennsylvania to be 20–40 times higher than a single minor source, although individual well operations generally fall below the major source thresholds. Adequate ambient air quality monitoring is necessary to characterize downwind impacts. The nature and extent of emissions produced by fracturing operations is partly controlled.
by market forces. Extremely low natural gas prices in recent years has made it uneconomical for producers to capture and process natural gas during fracturing operations and increased the amount that is flared into the environment.\textsuperscript{14}

In addition to non-attainment areas, several other shale plays (e.g., Eagle Ford) lie in close proximity to urban areas that are near-nonattainment (e.g., San Antonio and Corpus Christi), as a result, increased emissions due to fracturing coupled with unfavorable meteorological conditions may cause air quality exceedances in these areas.

Other Impacts and Risks
The construction of hydraulic fracturing pads and associated roadways can lead to habitat fragmentation. Groundwater production when carried out in shallow aquifers or near riparian areas can reduce water availability for wildlife as well as aquatic flora and fauna.\textsuperscript{15} Clear-cutting and deforestation associated with hydraulic fracturing can result in the loss of biodiversity and endanger critical habitats. A very visible impact of hydraulic fracturing operations is the increased truck traffic, which leads to congestion and increases the risk of accidents.

The Texas Department of Transportation, for example, recently reported that the number of large vehicle fatalities in the Eagle Ford region jumped from six in 2008 to 24 in 2012 and that there were nearly 3,500 crashes with fatalities or serious injuries in 2013. In addition to increased traffic, poor driving conditions due to road deterioration and fatigued oil field workers are noted to be the primary causes for the increase in travel-related risks.\textsuperscript{16} However, a standardized comprehensive multimedia risk/impact assessment guideline or standard has not been developed to date.

Technological Innovations
To minimize the environmental impact of hydraulic fracturing operations, technology innovations with respect to recycling and reusing flowback and produced water from hydraulic fracturing activity is needed. Currently, much of the flowback and produced water is injected in deepwater disposal wells, which is often cost-effective but effectively removes potentially useful water from the surface water cycle. The lack of salt water disposal wells in the Marcellus play areas has encouraged innovation and high rates of recycling of flowback and produced waters in those areas.
Treatment of flowback and produced water reduces the volume of water requiring disposal either to a publicly-owned treatment works (POTW) facility or an injection well, reduces water demand in drought stricken-areas, and reduces transportation requirements. Reuse also reduces the potential for environmental impacts from transportation accidents spills, reduces wear and tear on highway surfaces, while minimizing air pollution impacts from transportation. Research into flowback and produced water treatment has focused on the performance of individual treatment processes, as well as the performance of treatment technologies combined into treatment schemes. Membrane processes have been identified as a potential technology suitable for onsite treatment of flowback water due to the ease of mobility of modular membrane units and the ability of membranes to remove oils and other organics as well as salts. Membranes process such as forward osmosis and poly(ethyl glycol) (PEG)-coated ultrafiltration and reverse osmosis membranes demonstrated the ability to reduce the high salt concentrations of flowback water. The high salinity can lead to fouling, which impacts long-term treatment performance. Due to the high salt concentrations in flowback water, membrane technology may need to be paired with processes such as ion exchange to effectively reduce salt concentrations or pretreatment processes to minimize membrane degradation.

In addition to membrane systems, recycling technologies for flowback/produced water include thermal systems employing evaporation, distillation, or crystallization. For example, the NOMAD 200 MVR Evaporator system has been employed to process highly variable oilfield wastewater, resulting in a water recovery rate of 85%; and the Aqua-Pure ROVER Mobile Clarifier removes organics and suspended solids using coagulation and clarification technologies mounted onto trailers. These technologies can be energy intensive, but may prove beneficial if coupled with existing renewable sources such as solar and wind or make use of fracturing products (e.g., natural gas). Waste natural gas in oil production wells that is currently flared may be better used to provide energy for water treatment processes.

Federal and state air quality regulations can also have profound impact on unconventional oil and gas production.
Policy Instruments

Regulatory drivers also play a major role in fostering technological innovations. The availability of a large number of disposal wells in Texas, for example, makes the reuse of flowback and produced water not lucrative. Conversely, a 500 mg/L TDS discharge limit in Pennsylvania has increased pressure for flowback water treatment before reuse. Other policies, such as restricting the amount of oil and gas wastewater received by a POTW to not exceed 1% of the POTW’s average daily volume, have also spurred technological innovations.22 Also, some operators are developing fracturing fluids from flowback water.23

Work such as this demonstrates that high-quality water sources are not required for hydraulic fracturing operations and a reduced level of treatment may be an option for flowback water reuse and recycling. It also encourages the use of brackish water sources for hydraulic fracturing. However, policies exempting water use for oil and gas operations or providing conditional water rights for oil and gas development that supersede certain junior rights also serve to limit the reuse of flowback and produced waters. Water supply policies that provide credits for conservation and reuse are clearly beneficial in the arid southwestern shale plays.

Federal and state air quality regulations can also have profound impact on unconventional oil and gas production. The prevention of significant deterioration (PSD) in attainment areas and new source review (NSR) in non-attainment areas limit air quality emissions and require oil and gas producers to obtain a permit to operate equipment such as compressors that emit pollutants. However, the nature and extent of regulation depends upon whether the operations are classified as a major source or a minor source and the thresholds used to make this determination. Air quality regulations tend to be complex and controversies often arise in applicability and requirements interpretation.24 Steps are underway to promote the use of better technology and minimize air quality impacts. While not specifically focused on unconventional
oil and gas production, the National Emission Standards for Hazardous Air Pollutants (NESHAP) for stationary Reciprocating Internal Combustion Engines (RICE) rule, seeks to cut emissions from oil and gas. Voluntary partnerships, such as EPA’s Natural Gas STAR program, have led to the development of technologies that improve operational efficiencies and reduce methane emissions in oil and gas operations and are clearly steps in the right direction.

**Summary**

As with any other industrial activity, oil and gas production from unconventional sources entails environmental risks and as discussed here, these risks vary among shale plays. Technological and policy instruments can be used to manage and mitigate these risks. However, to be successful, they must be economically viable and accepted by the public. Adherence to best environmental management practices, minimizing emissions and releases, and maximizing use of non-potable waters, as well as recycling and reusing waters can all offset the environmental impacts of hydraulic fracturing for oil and gas. A standardized environmental impact assessment framework that allows for stakeholder participation would be useful to characterize and communicate environmental risks.