Shale Gas Exploration and Development: Geology and Economics at the Nexus of Water and Energy

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Introduction

The “Water-Energy Nexus” refers to the interdependence and competing development pressures for these two important natural resources (GWPC, August 2010). Together, economic and environmental factors influence the balanced exploration and conservation of water and energy. This is evidenced by the recent teaming arrangement involving the United States Departments of Energy, Environmental Protection, and Interior that was recently formed to ensure continued expansion of natural gas development in a safe and responsible manner (USDOE, April 13, 2012). The dynamics of this nexus are particularly evident in the recent proliferation of natural gas development of hydrocarbon-rich shale formations in the United States (GWPC and ALL Consulting, April 2009). Increased gas exploration has occurred due to technological advances in horizontal drilling technology combined with the established technology of hydraulic fracturing (Figure 1). The combination of these technologies has made the exploration of natural gas from shale formations, termed ‘unconventional natural gas’ economically viable.

The potential for economic growth and the prospect for energy independence represent exciting opportunities for our economy at-large and for geologists in particular. These opportunities are balanced by potential water resource and other geo-environmental pressures associated with modern shale gas development, which also represent opportunities for geologists. These include water use/disposal, gas leakage, groundwater contamination, and geohazards according to the Pennsylvania Geological Survey (Harper and Kostelnik, 2010). Geologists operate on both sides of this balance, and collectively our profession can help ensure the safe and economic development of energy while protecting our water resources. To do so, it will be necessary for geologists to bring technical insight to these issues across the spectrum of geologic specialties. The potential for technical collaboration and debate among geologists is expected and encouraged.

Overview of Shale Gas Exploration and Production

Natural gas has been produced from hydrocarbon-rich shale formations as early as 1821 in Fredonia, New York (GWPC and ALL Consulting, April 2009). Figure 2 presents a recent map of North American Shale Plays. The relatively low permeability of these formations inhibits economical production of natural gas, except when facilitated by the processes of horizontal drilling and hydraulic fracturing. Hydraulic fracturing involves the injection of water, commonly 2 to 4 million gallons, into shale formations at high pressure in order to artificially fracture the formation, increasing its permeability, and liberating natural gas from the formation. Though commonly employed as a technique for modern shale gas development, hydraulic fracturing is not a new technique. Hydraulic fracturing has been used since 1947 in oil and gas production (NGWA, November 2011). Water and sand typically constitute >99.5% of the fluid used for hydraulic fracturing (GWPC and ALL Consulting, April 2009). Sand is used as a ‘proppant’ in order to prop open and sustain fractures induced in the shale. Other additives, such as surfactants, friction reducers, scale inhibitors, and corrosion inhibitors constitute a fraction of a percent of the hydraulic fracturing fluid (GWPC and ALL Consulting, April 2009).

Drilling and fracturing of these shale formations occur at depths of several thousand feet, requiring the skills and expertise of geoscientists for safe, technologically effective, and economical operations. This highly technical process involves specialized techniques such as, geosteering to guide the drilling of the horizontal well; fracture modeling to design an optimal fracture spread that does not impact bounding formations; and, microseismic fracture mapping to plan and design additional explorations.

Figure 1 – Natural Gas Well Drill Rig, Wyoming

Figure 2 – North American Shale Plays. Source: United States Energy Information Administration
PROFESSIONAL CONTRIBUTIONS

Water Resource Considerations

According to the United States Geological Survey, groundwater constitutes 99% of the Earth’s freshwater that is available for human use, and the United Nations estimates that 54% of accessible freshwater is being appropriated for human use, and that by 2025 this demand will increase by 50% in developing countries and by 18% in developed countries.

Hydraulic fracturing is water intensive, requiring large volumes of water. Subsequent to hydraulic fracturing, injected and formation water returns to the surface initially as flow back water and subsequently as produced water. This water is typically characterized as brine, and may include hydrocarbons, dissolved metals, and low-level naturally occurring radioactive material (NORM), posing a water management issue. Disposal and management options for flowback water include disposal in underground injection disposal wells, processing water at treatment facilities, and recycling/reuse for hydraulic fracturing and other uses.

The potential for direct impact to aquifers due to hydraulic fracturing has been a concern of the public. However, The National Ground Water Association (NGWA), in its position paper, Hydraulic Fracturing: Meeting the Nation’s Energy Needs While Protecting Groundwater Resources (NGWA, November 2011), recognizes that hydraulic fracturing is a mature technology that has been implemented for many years, and that there is no definitive documentation of wide-spread impact to groundwater supplies due to hydraulic fracturing (NGWA, November 2011). The NGWA does note that incidental activities may potentially impact groundwater near shale gas production sites. These activities include improper well construction or abandonment of both natural gas and water wells; increased use of groundwater associated with oil and gas operations; and improper management and disposal of wastewater.

Similarly, the New York State Department of Environmental Conservation (NYSDEC) does not anticipate potential impacts to groundwater that are directly due to the high-volume hydraulic fracturing (NYSDEC, September 7, 2011). The NYSDEC document, Revised Draft: Supplemental Generic Environmental Impact Statement on the Oil, Gas, and Solution Mining Regulatory Program, does recognize the potential for environmental impact due to incidents, spills, and releases associated with surface activities (e.g., fuel storage, flow back water storage/management, drilling mud pits, centralized impoundments, and storage of frac chemical additives).

The Role of Geologists

As technical professionals involved with all aspects of the water-energy nexus of shale gas development and water resource management, geologists are positioned to play a pivotal role in ensuring economic growth and energy independence in a way that is protective of our water resources. Geoscience specialties involved in this endeavor include those listed in Table 1.

With estimates of modern shale gas production projected to be sustained for years, the need for geologists is expected to be sustained by this industry for the foreseeable future. Undoubtedly, geologists will continue to play an important role as technical professionals responsible for ensuring the balanced protection, exploration, and production of our critical resources: natural gas and water.

Table 1.

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<tr>
<th>Geologic Specialty</th>
<th>Example Roles and Contributions</th>
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<tr>
<td>Petroleum Geologist</td>
<td>Conducts field activities such as core and mud logging. Provides technical evaluation of natural gas drilling prospects, including formation properties and gas quantities.</td>
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<tr>
<td>Geophysicist</td>
<td>Supports natural gas exploration through subsurface mapping and borehole logging via geophysical methods.</td>
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<tr>
<td>Engineering Geologist</td>
<td>Supports geotechnical investigations for natural gas infrastructure and horizontal directional drilling for pipelines.</td>
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<tr>
<td>Seismologist</td>
<td>Evaluates claims of seismic disturbance.</td>
</tr>
<tr>
<td>Hydrogeologist</td>
<td>Identifies potential water sources; provides consultation for groundwater protection measures; investigates claims of impacted groundwater; provides technical support and analysis for deep injection of wastewater.</td>
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Recent Research and Legislative Activity – Pennsylvania Case Study

Pennsylvania has a rich oil and gas heritage that started with the first oil well drilled in Venango County by Edwin L. Drake in 1859. Since that time, oil and gas drilling activity would subside and return in this area of Pennsylvania many times (Pees and Stewart, 1995). Circa 1995, a decade before the proliferation of unconventional shale gas drilling in Pennsylvania, oil and gas operations in the area of the historic Drake well consisted of pluging old, abandoned, shallow, pressure-depleted wells; shallow, pump-production in limited areas; and natural gas development from deep wells (>6,000 feet deep) on the flanks of the lower Silurian Medina Group (Pees and Stewart, 1995).

According to the Pennsylvania Geological Survey (Harper and Kostelnik, 2010), modern development of the Marcellus Shale began in 2004 with the drilling of a Marcellus Shale well in Washington County and subsequent testing of hydraulic fracturing as a stimulation technique. From this point, unconventional natural gas exploration rapidly expanded, as did concerns about the concurrent protection of water resources.

Researchers from Penn State University recently published the results of a study entitled, The Impact of Marcellus Gas Drilling on Rural Drinking Water Supplies (Boyer, E.W. et al., October 2011). The study was funded by The Center for Rural Pennsylvania, which is a legislative agency of the Pennsylvania General Assembly. The objective of the research effort was to conduct an unbiased and broad-scale study comparing water quality associated with water supply wells before and after natural gas drilling and hydraulic fracturing in the Marcellus Shale. Notable conclusions from this report are listed below:

- Statistical analysis does not suggest major influences from gas well drilling or hydraulic fracturing on nearby water wells.
- 20% of water wells had detectable methane concentrations prior to drilling.
- No statistically significant increases in methane levels were identified.
- Approximately 40% of the water wells failed Safe Drinking Water Act criteria prior to gas well drilling.
Construction standards, including but not limited to:

Exploration and development of natural gas from the Marcellus Shale in Pennsylvania has been active for several years. Consider also that groundwater is the potable water source for 4.5 million Pennsylvanians (Giddings, 2012). These facts and the results of the Penn State study corroborate the position of the NGWA that proper installation, construction and maintenance of natural gas wells and water supply wells is necessary to protect groundwater supplies. Pennsylvania is one of only two states that do not have private water well construction regulations (Boyer, et al., 2011). Recently promulgated legislation for natural gas wells (Act 13 of 2012) and pending legislation for groundwater supply wells (House Bill 1855) are expected to collectively protect groundwater supplies in Pennsylvania. This is consistent with the suggestions of the NGWA position paper that groundwater protection efforts should address both natural gas and water supply wells.

Legislation focused on unconventional natural gas wells, was recently passed in Pennsylvania to provide additional measures of protection to water supplies. Pennsylvania Act 13 of 2012 includes the following provisions for the protection of water supplies and groundwater supply wells:

- During the permitting process for unconventional natural gas wells, water supplies within 3,000 feet of a proposed unconventional natural gas well must be identified, and water purveyors within this distance must be notified;
- Unconventional natural gas wells are prohibited from being drilled within 500 feet of an existing water well and 1,000 feet of a public water supply source;
- Operators of unconventional natural gas wells are presumed to be responsible for pollution of a water supply, if the water supply is within 2,500 feet of the unconventional natural gas well, and the pollution occurred within 12 months of completing, drilling, stimulation, or alteration of an unconventional natural gas well.

Interestingly, increased offset distances between natural gas wells and public water supplies, intended to protect water quality, have increased economic and geographic pressures on the water-energy nexus for some municipal water purveyors. Specifically, land owners in rural gas producing areas have greater economic incentive to lease their land for natural gas development than they do for rural water supply wells. Additionally, the increased offset distance, separating unconventional gas wells from public water supply wells, limits the availability of suitable water supply well locations when there is greater economic incentive to produce natural gas. This leads to another paradox: the demand for water is expected to increase in areas experiencing economic and population growth due to natural gas development. In some circumstances, this situation puts both water purveyors and natural gas producers in opposition to these offset measures that are intended to be protective of public water supplies.

Pending legislation for water well construction standards in Pennsylvania is expected to benefit the protection of groundwater in this gas-producing state. Pennsylvania House Bill 1855 was introduced by Representative Ronald Miller on December 7, 2011. House Bill 1855 outlines a framework for water well construction standards, including but not limited to:

- Well site selection
- Casing and casing installation
- Well screens, filter packs, and formation stabilizers
- Grouting
- Performance testing
- Well sampling and analysis.

This legislation is supported by the Pennsylvania Ground Water Association, Pennsylvania Council of Professional Geologists, Pennsylvania Department of Environmental Protection, and a member of the Penn State Extension Program (Giddings, 2012).

Conclusions

Development of unconventional natural gas from hydrocarbon-rich shale formations is expected to continue into the foreseeable future due to 1) global demand for energy, 2) abundant shale gas reserves, and 3) the technology to economically develop this resource. This combination of factors creates opportunities for economic growth, as well as energy independence. This opportunity is balanced by its interdependence and competition with water as an equally important natural resource that is also experiencing increased demand. Geologists find themselves at the water-energy nexus, being directly involved with projects focused on natural gas exploration, transmission, water supply development, and water resource protection. Consequently, geologists are expected to play a vital role in ensuring safe and economical use of our natural gas and water resources into the future.

References

Boyer, Elizabeth; Swistock, Bryan; Clark, James; Madden, Mark; Rizzo, Dana, October 2011, The Impact of Marcellus Gas Drilling on Rural Drinking Water Supplies, The Center for Rural Pennsylvania, 29 p.


