Paper #2-29

HYDRAULIC FRACTURING: TECHNOLOGY AND PRACTICES ADDRESSING HYDRAULIC FRACTURING AND COMPLETIONS

Prepared for the
Operations & Environment Task Group

On September 15, 2011, The National Petroleum Council (NPC) in approving its report, *Prudent Development: Realizing the Potential of North America's Abundant Natural Gas and Oil Resources*, also approved the making available of certain materials used in the study process, including detailed, specific subject matter papers prepared or used by the study's Task Groups and/or Subgroups. These Topic and White Papers were working documents that were part of the analyses that led to development of the summary results presented in the report's Executive Summary and Chapters.

These Topic and White Papers represent the views and conclusions of the authors. The National Petroleum Council has not endorsed or approved the statements and conclusions contained in these documents, but approved the publication of these materials as part of the study process.

The NPC believes that these papers will be of interest to the readers of the report and will help them better understand the results. These materials are being made available in the interest of transparency.

The attached paper is one of 57 such working documents used in the study analyses. Also included is a roster of the Task Group for which this paper was developed or submitted. Appendix C of the final NPC report provides a complete list of the 57 Topic and White Papers and an abstract for each. The full papers can be viewed and downloaded from the report section of the NPC website (www.npc.org).

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EXECUTIVE SUMMARY

Hydraulic fracturing an oil or gas well stimulates production and provides the industry a means to increase recovery of the hydrocarbon resource economically. Use of hydraulic fracturing can provide an effective means to lessen environmental impacts from the development of oil and gas resources, and makes resources economically feasible assets.

Hydraulic fracturing has become an integral part of oil and gas development across the United States. Production increases from this technology dramatically reduce the environmental footprint of oil and gas development while economically commercializing historically undevelopable resources. The 60-year historical development of hydraulic fracturing shows how the technology has evolved as a response to many drivers, including development of different resource types and diverse locations, environmental impact concerns, costs and economics, and regulatory considerations. Today, when the technology is used on up to 95% of new wells, hydraulic fracturing design is continuously refined and modified to optimize fracture networking and to maximize resource production.

While the concept and procedures for hydraulic fracturing are similar across all resource types, variations in design occur between locations and resources. Offshore development presents unique challenges that are different than onshore challenges, with differences in water sources, chemical additive composition, and disposal opportunities. Shale gas wells drilled using horizontal drilling technologies often require larger fracturing volumes and more stages than vertically drilled wells. This paper discusses these and additional variations, as well as how innovators are exporting the lessons learned in resource plays to other potential development areas.

Concerns over the environmental impacts associated with hydraulic fracturing have led to extensive research and studies. Air emissions, surface water and ground water withdrawals, produced water management, surface impacts, biological impacts, vibrations, noise, and visual and community impacts have all been cited as potential problems by individuals and organizations concerned about the possible environmental consequences of hydraulic fracturing. However, as hydraulic fracturing technology has progressed, operators and regulators have identified and developed extensive mitigation measures to alleviate potential adverse impacts.

While the economic benefits of hydraulic fracturing are evident in the recent increases in the nation's natural gas supply, there are also economic disadvantages to the technology. The main disadvantage is the expense of the operation; operators are continuously trying to find measures to control the increasing costs of fracturing that add to the cost of energy. The future influence of hydraulic fracturing technology on the industry and energy market could be staggering as new sources of unconventional hydrocarbon resources are discovered and exploited. New advances in the technology in the areas of green chemistry, water management, hydraulic fracturing design and job management, and success tracking are expected to extend the prosperity and productivity of this technology and its advancement into the future.

Several barriers, such as regulatory uncertainty, economics, technology limits, and water availability, could influence the oil and gas industry as a whole and regional development specifically. This paper discusses the barriers to the use of hydraulic fracturing today and in the future as well as opportunities and considerations for the future use of the technology.

Complicated regulations at multiple governmental levels could hinder hydraulic fracturing's technological advancment. As hydraulic fracturing is applied to unconventional resources in previously undeveloped areas, it has become the focus of many regulatory modifications at the federal, regional, state, and local levels. Although hydraulic fracturing is currently regulated at all of these levels (most prominently the state), many groups and individuals have called for additional federal regulation under the Underground Injection Control (UIC) program. The United States Environmental Protection Agency (U.S. EPA) has a study underway on hydraulic fracturing's potential impact on drinking water resources. In order to promote the technology, the complicated regulatory labyrinth should be streamlined, yet cannot be over-simplified to a single approach that will not take into account the geological and technological differences between plays necessary to effectively produce the hydrocarbon resources.

Economic barriers that must be considered arise from the costs of the operation itself, the cost of water management, and the increased research costs associated with developing the technology to meet future demands. Recently reuse and recycling of produced water has been identified as a means to decrease the costs associated with acquiring and transporting source water and can also minimize the impacts associated with water withdrawals. These types of advancements need to be encouraged through incentives on more research.

There are multiple technological and environmental barriers associated with the hydraulic fracturing process. In some areas, only a fraction of the water used in hydraulic fracturing operations is recovered as produced water. This can affect the success of a fracture job. In order to sustain sufficient levels of development, it is imperative that advancements in chemical additives providing the ability to use less water and recover more of the water used be developed. Once the water is produced, disposal can also be a challenge.

Encouraging the use and development of green chemicals should continue for future hydraulic fracturing success. Part of this process needs to include the assurance that intellectual property rights will be protected. Without this assurance, companies will be hesitant to invest money into advanced research opportunities. Many states require chemical disclosure of hydraulic fracturing fluids, to varying degrees. It is essential that regulators and companies find ways to maintain proprietary information and competitive advantages while expanding the technology and protecting the health of workers and land owners. Future developments in hydraulic fracturing will likely include techniques for more efficient water usage, the use of a larger number of environmentally benign chemicals, active treatment systems and movement away from high volume water fracturing to foam fluid fracturing or other technologies such as sonic or microwave technologies. Monitoring and simulation technologies will likely become more advanced, leading to further advancements in fracture designs in the future. Advancement will further refine the fracturing process, overcome barriers, and present new and innovative opportunities in the future.

This report identifies the following findings relative to the implementation of hydraulic fracturing:

- Current oil and gas production in the United States is highly dependent on hydraulic fracturing (HF) technology. In fact, most hydrocarbon-bearing reservoirs within the U.S. cannot sustain commercial production levels without hydraulic fracturing.
- Hydraulic fracturing is a well established technology with over 60 years of implementation and over 2 million separate fracturing treatments.
- Dramatic and fruitful environmental improvements in today's technology are rapidly increasing, leading to a sustainable and economically viable energy supply. Fluids in the industry today, including HF fluids, show a consistently declining health, safety, and environmental impact.

INTRODUCTION

A. Definition of Hydraulic Fracturing

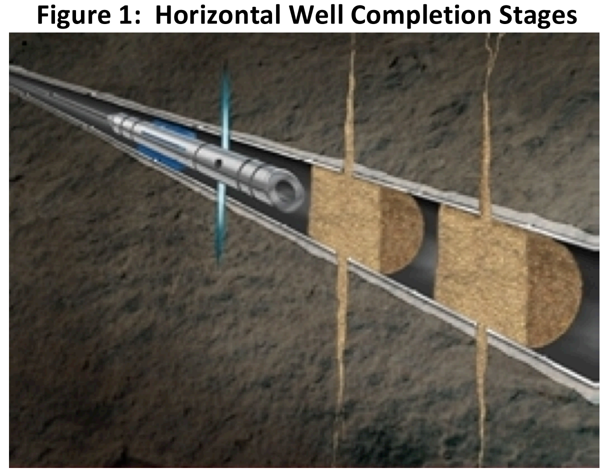
Hydraulic fracturing is defined as:

> The process of pumping into a closed wellbore with powerful hydraulic pumps to create enough downhole pressure to crack or fracture the formation. This allows injection of proppant[a] into the formation, thereby creating a plane of high-permeability sand through which fluids can flow. The proppant remains in place once the hydraulic pressure is removed and therefore props open the fracture and enhances flow into the wellbore (Schlumberger, 2011a).

Hydraulic fracturing has dual objectives: to increase the rate at which a well is able to produce oil or gas and to increase the economically recoverable reserves for a well.

Typically the technology is used during the initial completion process of the well, and its costs are associated with the drilling of the well. It should be noted that hydraulic fracturing can also occur after the initial completion of a well, when it is believed that stimulation of the well could provide additional economic benefit. Figure 1 shows a cross-section diagram of a horizontal well with multiple completion stages where pathways have been created and filled with proppant.

Figure 1: Horizontal Well Completion Stages



Source: Halliburton Energy Services, Inc., "Well Stimulation Technology" (January 2011).

[a] A proppant is a granular substance held in suspension by the fracturing fluid that aids in keeping the fractures open once the hydraulic pumps are stopped [Schlumberger online Oilfield Glossary, "Proppant" (©2011), http://www.glossary.oilfield.slb.com/Display.cfm?Term=proppant (accessed February 8, 2011).]

B. History of Hydraulic Fracturing in Oil and Gas Industry

This section presents historic drivers that have had influence on the development of hydraulic fracturing technology. The first experimental hydraulic fracturing treatment was performed in Grant County, Kansas, in 1947 by Stanolind Oil (Montgomery and Smith, 2010). A limestone formation at approximately 2,400 feet below ground level was fractured using a total of 1,000 gallons of naphthenic-acid and palm-oil thickened gasoline, followed by a gel breaker. Following the experiment, an industry paper was written by J.B. Clark of Stanolind Oil introducing the technology and in 1949, a patent was issued granting Halliburton Oil Well Cementing Company the exclusive right to pump the new "Hydrafrac" process (Montgomery and Smith, 2010).

The first commercial application of hydraulic fracturing was in performed on March 17, 1949, on a well approximately 12 miles east of Duncan, Oklahoma. The same day, a second well was hydraulically fractured near Holliday, Texas. In the first year, 332 wells were hydraulically fractured with the new technology, with an average production increase of 75%. Since then, more than 2 million hydraulic fracture stimulations have been completed (Fisher, 2010).

FACTORS THAT GOVERN USE OF HYDRAULIC FRACTURING

A. Operational Drivers

Since the first commercial "Hydrafrac" application, the hydraulic fracturing process has undergone several technological advances to adapt to the proposed development of different quality reservoirs and also to adjust to advancements in other areas of development, such as the onset of horizontal drilling. The first fracture treatments averaged approximately 750 gallons of fluid and 400 pounds of sand. Today, treatments can exceed 1 million gallons of fluid and 5 million pounds of proppant (Montgomery and Smith, 2010).

Originally, fracturing operations were performed with gelled crude, followed by kerosene and the use of refined and crude oils. In 1952, developers began to use water as a fracturing fluid and identified the need for gelling agents to thicken the water to allow for proppant suspension during the stimulation. In the years to follow, additional additives, including surfactants, clay-stabilizing agents, and metal cross-linking agents, were patented to make hydraulic fracturing treatments more efficient and successful. Today, aqueous fluids such as acid, water and brines make up approximately 96% of all fracturing treatments that use a propping agent (Montgomery and Smith, 2010).

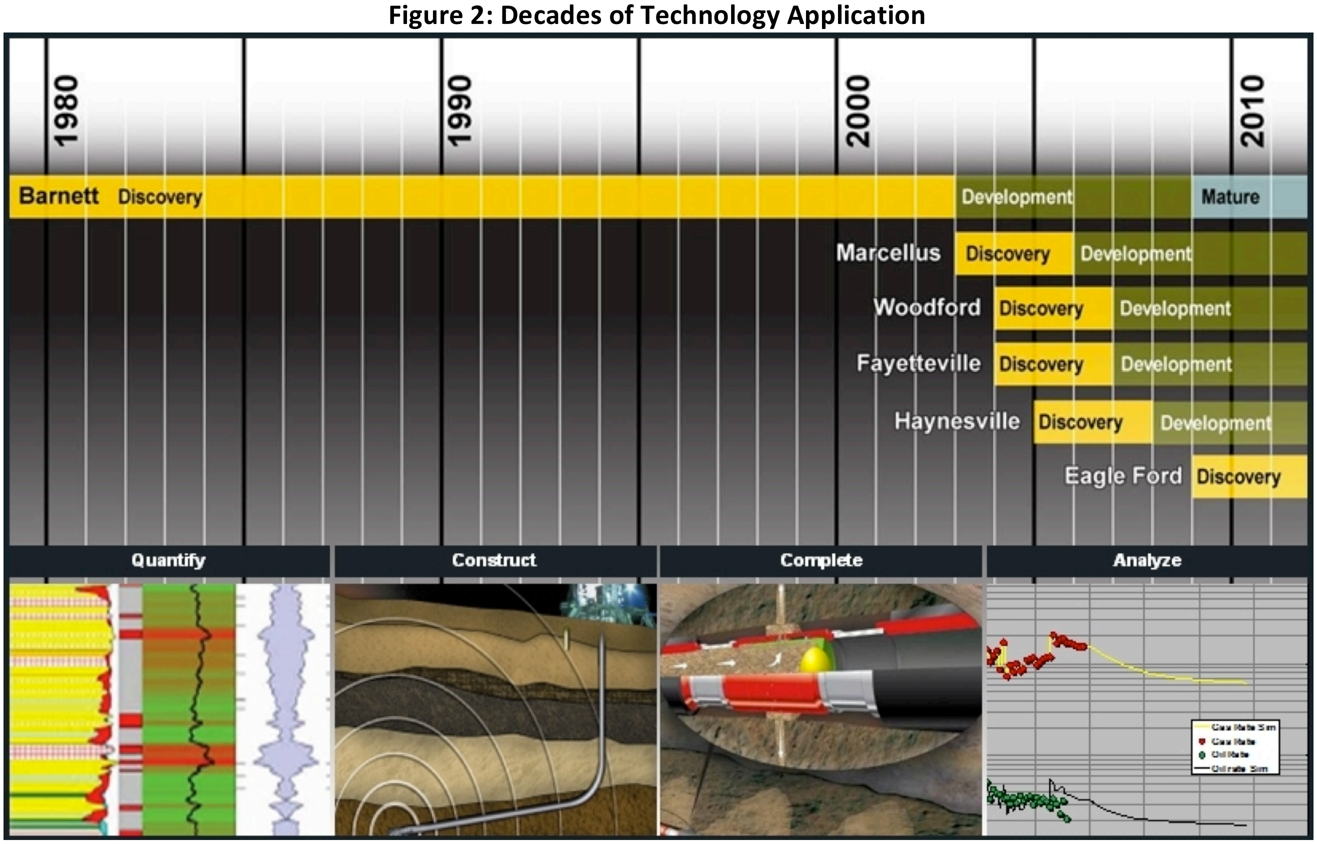
Numerous propping agents have been used throughout the years, including plastic pellets, steel shot, Indian glass beads, aluminum pellets, high strength glass beads, rounded nut shells, resin coated sands, and others, but from the beginning, standard mesh sand has been the most popular (Montgomery and Smith, 2010). Initial sand concentrations were low, but have been continuously increasing, with a spike in recent years due to advances in pumping equipment and improved fracturing fluids (Montgomery and Smith, 2010).

Hydraulic fracturing designs are constantly being refined to optimize fracture networking and to maximize resource production, while ensuring that fracture development is confined to the target formation for both horizontal and vertical wells (Boyer et al., 2006). Initial treatments were designed using complex charts, monographs, and calculations (Montgomery and Smith, 2010). Modern formation stimulation practices have become more complex and the process has developed into a sophisticated engineered process in which production companies work to design a hydraulic fracturing treatment to emplace fracture networks in specific areas (Boyer et al., 2006).

The latest advances in hydraulic fracturing design utilize technologies such as computer simulations, modeling, microseismic fracture mapping and tilt measurements for analysis of hydraulic fracturing treatments (Lecampion, 2006). These technologies can be used to define the success and orientation of the fractures created, thus providing the engineers the ability to manage the resource through intelligent placement of additional wells to take advantage of the natural conditions of the reservoir and expected fracture results in new wells.

Coupled with the advancements in hydraulic fracturing has been the advancement of horizontal drilling. In combination, these technologies have proven a successful means to economically develop unconventional tight and shale gas resources. Horizontal drilling was used as early as the 1930s, but like hydraulic fracturing, the process has been continually modified and improved. By the 1980s, horizontal drilling became a standard industry practice (Harper, 2008). The combined technologies were successfully applied to the Barnett shale in Texas and have since been duplicated in other shale gas basins such as the Marcellus, the Haynesville, and the Fayetteville, making previously undevelopable resources some of the largest natural gas-

Figure 2: Decades of Technology Application



Source: Halliburton Energy Services, Inc., "Well Stimulation Technology" (January 2011).

producing fields in the country. To advance the technology, the industry has had to learn lessons in quantification, construction, completion, and analysis. **Figure 2** shows that, and presents a timeline of shale gas development. The development of new technologies has enabled the production from shale formations.

B. Legislative/Regulatory Drivers

The development and progression of hydraulic fracturing has been influenced significantly by legislative and regulatory drivers. The Safe Drinking Water Act (SDWA) was enacted in 1974, 25 years after the commercial onset of hydraulic fracturing operations. Hydraulic fracturing was not considered for federal regulation under the SDWA during drafting and has never been federally regulated. Public concern and opposition to the technology and regulatory framework have become more prevalent over the last decade, and coupled with the industry response to public concerns, have been primary drivers in the progression of hydraulic fracturing technology and regulation as it stands today and into the future. Table 1 outlines the drivers of hydraulic fracturing since the passage of the SDWA.

Table 1: History of Hydraulic Fracturing Regulation

Year	Action	Entity	Comments
1940s to present	Adoption of state natural gas and oil regulatory programs	All natural gas and oil producing states, including OK, TX, LA, CO, WY, PA, etc.	States have adopted their own comprehensive laws and regulations to protect drinking water supplies including the regulation of hydraulic fracturing. These states' programs have been refined over the years, as necessary, to address industry changes.
1974	Safe Drinking Water Act (SDWA)	US Environmental Protection Agency (US EPA)	Act drafted to protect health by regulating nation's public drinking water supply.
1996	Legal Environmental Assistance Foundation, Inc. (LEAF) vs. EPA U.S.	US EPA	Alabama regulation of hydraulic fracturing in CBNG stimulations under the Underground Injection Control (UIC) program.
2003	Memorandum of Understanding (MOU) between US EPA and service companies	US EPA	Major service companies agree to refrain from using diesel fuel in hydraulic fracturing fluids in stimulations involving underground sources of drinking water (USDWs) associated with CBM wells.
2004	Evaluation of Impacts to USDWs by Hydraulic Fracturing of CBM Reservoirs Final Report	US EPA	Study evaluated potential threat to USDWs from injection of hydraulic fracturing fluids into CBM wells. Concluded that injection of hydraulic fracturing fluids into CBM wells poses minimal threat to USDWs.
2005	Energy Policy Act	US House	Clarified that hydraulic fracturing (exception for diesel fuel) was not underground injection as defined in SDWA
2009	Frac Act Introduced	US Congress	Act would require chemical disclosure of hydraulic fracture fluid additives.
2010	Wyoming natural gas and oil Regulations	State of Wyoming	Full chemical disclosure of fracturing fluids regulations put into place
2010	State Regulations	Various	Multiple State regulatory bodies and legislators studying or enacting regulations on disclosure of hydraulic fracturing fluids
2010	Hydraulic Fracturing Study	US EPA	EPA announces commencement of a new study investigating the possible relationships between hydraulic fracturing and drinking water.

Year	Action	Entity	Comments
2011	Establishment of SEAB (Secretary of Energy Advisory Board) Natural Gas Subcommittee	U.S. DOE	The frack panel was established to provide recommendations to the SEAB on how to improve the safety and environmental performance of natural gas hydraulic fracturing from shale formations.
2011	EPA Regulation Review	US EPA	EPA initiates process to develop guidance for diesel use in UIC operations.

C. Resource Location/Geological Drivers

The technological development of hydraulic fracturing has been greatly influenced over time by the need to address specific resource locations and geological barriers to extraction of oil and gas. In short, there is no single hydraulic fracturing technique that is equally optimum for all applications. Variations in reservoir properties require tailoring of specific techniques. Later in this paper a discussion is presented on these drivers and the technological advancements made.

D. Public Perception Drivers

Public perception has the ability to shape a technology through the use of regulations, policies, and best management practices. Historically hydraulic fracturing technology itself had been immune to the influences of public perception with most pressures being applied on the industry as a whole. Not until more recent times (i.e., the past 10 years of its 60-plus year history) has the influence of public perception and Environmental Non-Governmental Organizations (ENGOs) applied specifically to hydraulic fracturing. Pressure by the public and media and the desire of the industry to address the concerns are driving development of even more environmentally friendly measures, materials and practices.

Public perception of hydraulic fracturing centers around increased air emissions, water sourcing and availability, produced water management, surface impacts, biological impacts, vibration, noise impacts, visual impacts, and community impacts. In areas where water sources are scarce or over allocated, the use of water for hydraulic fracturing creates concerns that the source water is consumptively lost to the system, eliminating the potential for future use in other sectors.

The hydraulic fracturing procedure itself creates public concern. Some of the apprehensions surround the use of chemical additives in the stimulation itself, representing fear that the chemicals will migrate to drinking water supplies through vertical fractures or cement and casing failures. Other anxieties arise from the lack of knowledge of hydraulic fracturing operations itself and are intensified by opponents of the technology.

The disposal of produced water is also a public concern, primarily due to the chemical constituents used in hydraulic fracturing fluids. The protection of proprietary information and lack of requirement for chemical disclosure leads to the lack of trust between industry and the public. Chemical disclosure has been at the center of many ENGO complaints. While industry does not typically refuse to disclose chemicals, there is a disconnect relative to the level of disclosure required and to whom. ENGOs and other public entities desire public disclosure for every wellbore to every interested party while industry representatives believe that disclosure to regulatory agencies and medical personnel is sufficient.

An increase in seismic activity in areas where hydraulic fracturing and disposal is occurring has led many to deduce that earthquakes are the result of hydraulic fracturing. While studies are being evaluated to determine if there is a connection, some groups are demanding the halt of hydraulic fracturing operations until further information is gathered.

Other concerns, such as those about visual, noise, and community impacts, are not necessarily limited to hydraulic fracturing operations. These concerns are the focus of ENGOs and the public relative to all facets of the oil and gas industry as well as other energy industries.

E. Industry Benefit of Use

While certain aspects of hydraulic fracturing technology have been changing and maturing since its initial use (e.g., changes in the additives and propping agents, design and monitoring), this technology has continually been utilized by the industry to increase the production and ultimate recovery of resources. Use of the technology has been paramount to the successful production of oil and gas and many oil and gas fields would not exist today without the use of hydraulic fracturing (Montgomery and Smith, 2010).

Benefits to the industry and to the country can be immediately observed based on the increase in proved reserves. The increase in U.S. proved reserves of natural gas – from 164.42 trillion cubic feet (Tcf) in 1994 to 284 Tcf in 2009 2009 (EIA, 2010a) – is primarily the result of advances in hydraulic fracturing and horizontal drilling (Beckwith, 2010). This increase in reserves is continuing to occur with the expanded exploration of unconventional gas resources. Hydraulic fracturing has aided in the extraction of more than 7 billion barrels of oil and 600 Tcf of natural gas over the years (IOGANY, 2011). Up to 95 percent of current operating wells are being hydraulic fractured to remain commercially viable (Energy in Depth, 2010).

VARIATIONS BASED ON LOCATION AND RESOURCE TYPE

Enhancement to hydraulic fracturing technology has occurred because of multiple drivers. This section outlines the advancements based on the needs specific to certain location and geologic needs. Ultimately, advancement of the technology has focused on increasing the efficiency and effectiveness of the process while decreasing the environmental footprint, with the goal to increase the economically recoverable reserves of a well.

A. Onshore Development

Generally, in the onshore environment, technological advancements to hydraulic fracturing have focused on reducing costs and increasing recoverable reserves. Hydraulic fracturing technology has matured in the onshore conventional oil and gas environment, providing the industry an ability to test and develop new techniques and materials. The development of new technologies over the history of hydraulic fracturing has occurred in many areas, including chemicals, proppants, perforation placement, well completion techniques, design techniques, modeling and monitoring of hydraulic fracturing jobs. Each job performed advances the technology and helps to enhance the understanding of hydraulic fracturing. These advancements have been translated to the other environments discussed in this section and provide a base set of technological advancements for the implementation of hydraulic fracturing in those environments (Economides and Nolte, 1989).

B. Offshore Development

Hydraulic fracturing from offshore platforms presents environmental and operational challenges beyond the challenges of hydraulic fracturing onshore. Although the premises of fracturing and creating flow paths for the resources to be produced are the same, there are unique barriers to overcome in the offshore environment. Two primary differences between stimulation procedures offshore versus those onshore are the qualities of the source water available and of water to be discharged (Baycroft et al., 2005). Source water for fracturing offshore has been composed mainly of seawater and as such chemical additives have had to be developed that are compatible with seawater. These advancements in fracturing fluids have helped to advance the practice of reuse of produced water (Halliburton, 2003).

Relative to the disposal of produced water, fracturing fluids and additives must meet or surpass environmental regulations for marine discharge while maintaining performance characteristics. This has led to the advancement of more “green” chemicals for use in hydraulic fracturing. Historically onshore produced water has been disposed through cost effective means such as injection wells. Engineering the chemicals to meet the environmental regulations for the offshore environment and still meet the needs of the hydraulic fracturing job has helped to support advancements in other resource areas where water disposal options are limited.

Other factors beyond the environmental regulations have affected the development of chemicals and processes used in hydraulic fracturing offshore. These factors include depth of the wells, temperatures at depth, and pumping pressures due to limitations in equipment. Higher temperatures and well depth require chemicals such as cross-linkers to be modified and pumped in a different fashion to prevent precipitates from forming and from increasing the limited pumping pressures.

C. Resource Types

Both the demand to produce more oil and gas and the rise in the commodity price have been factors in increasing the exploration and development of less conventional resource plays. Through the advancement of horizontal well drilling and “slickwater” high volume hydraulic fracturing the ability to produce these unconventional resource plays in an economic means have become viable options. For example, the first Barnett shale well was drilled in 1981. In the 20 years to follow, experiments, primarily with hydraulic fracturing, were conducted to identify the recipe for the successful expansion of development that occurred in 2003 (Brackett, 2008). Still no two basins or resources are the same and variations need to be explored and evaluated for optimizing the hydraulic fracturing processes that works best by area (Montgomery and Smith, 2010).

Development of unconventional energy resource plays, including coal beds, tight sands and shale, has been a growing source of oil and gas development in the United States. Since 1998 unconventional natural gas production has increased nearly 65%. It was recently predicted that the State of North Dakota could surpass Alaska on annual oil production based on its Bakken Shale play (MacPherson, 2011). This increase has resulted in unconventional production becoming an increasingly larger percentage of total domestic resource production (EIA, 2010b).

The technological developments specific to hydraulic fracturing that have been the drivers for the successful exploitation of these resources have been:

- Slickwater fracturing (SWF), a process developed in the Barnett Shale in the Fort Worth Basin where very few additives are added to the fracturing fluids – SWF lowered fracturing cost, penetrated natural fractures and increased undamaged fracture connectivity to the wellbore. Propping ability did suffer without gels to carry proppant (King, 2010).
- Multiple fracture stages (upwards to 10 to 20) along horizontally drilled wellbores – This provides increased contact with shale formation and increased improved recovery (King, 2010).
- Simultaneous or sequential fracturing of multiple wells – This uses real-time stress changes created by previous fracturing events in adjacent wells to increase improvements in productivity over single well fracture treatments (King, 2010).

Petroleum industry innovators continue to export lessons learned at one resource-play to other resource-plays. That cross-fertilization of capabilities has led to development activity in geographic areas that have not historically seen oil and gas development (Walser and Pursell, 2007).

Coal bed natural gas (CBNG) wells may also undergo hydraulic fracturing to stimulate production. However, unlike most conventional gas wells or shale gas wells, some aquifers associated with CBNG reservoirs may contain high quality groundwater, potentially suitable as a potable water supply source. Therefore, States have adopted special rules about the use of hydraulic fracturing of CBNG wells that are within aquifers. These rules have been put into place to provide additional protection to the drinking water source (STRONGER 2010 and Alabama 2003).

ENVIRONMENTAL MANAGEMENT AND BENEFITS

Table 2 summarizes the direct and indirect factors involved in mitigating the environmental issues that are associated with hydraulic fracturing. In addition to the direct factors, widely recognized as the volumes, compositions and fates of fracturing fluids, there are indirect factors that include transportation and other support activities necessary to accomplish the fracturing work.

Environmental Issue	Impact	Mitigation Measures
Air Emissions	Truck traffic emissions	• Locating source water near well site • Installing temporary pipelines • Water recycling
	Diesel Engines	• Smaller, more powerful engines • Solar powered battery operating components
	Produced Fracturing Fluids	• Monitoring for ozone • "Green" completions • Closed-Loop Systems
Water Sourcing: Surface Water	Stream flow, fish, aquatic organisms, wetlands, terrestrial habitat	• Selective withdrawal locations • Ensuring sufficient flow capacity before withdrawals • Capturing water during high surface flows
	Municipal and Industrial water supplies	• Ensuring sufficient flow capacity before withdrawals • State / local agency permitting
Water Sourcing: Groundwater	Salt water intrusion Contamination from surface Lower water levels Release of free gas	• Monitoring to assure safe levels are maintained
Produced Water Management	Storage in pits can impact groundwater	• Use above-ground tanks in lieu of pits • Line pits and use leak detection systems • Groundwater monitoring wells • Construct and design impoundments to provide structural integrity
Surface Impacts	Land disturbance	• Multi-well pads • Centralized fracturing facilities
Biological impacts	Wildlife and Habitat Impacts	• State regulations, local ordinances and lease stipulations • Restrictions on development • More stringent permitting • Timing restrictions for operations
Vibration	Seismic events	• Investigation of injection wells • Monitoring of injection rates
Noise	Vehicle Traffic Noise	• Reuse of produce water • Use of temporary above ground pipelines
	Fluid Handling and Pumping Noise	• Maximizing distance from human and wildlife receptors • Timing restrictions for operations • Directing noise equipment away from receptors • Artificial or natural sound barriers
Visual	Trucks and Equipment	• Address impacts during design phase • Setback requirements • Directional lighting • Centralized fracturing facilities

Environmental Issue	Impact	Mitigation Measures
Community Impacts	Traffic volume increases	• Avoidance practices • Timing restrictions for operations • Temporary Above Ground Pipelines
	Road Damage	• Road Maintenance and Repair Agreements • Temporary Above Ground Pipelines
	Dust	• Water unpaved roads for dust abatement
	Noise	• Sound barriers

A. Air Emissions

Air pollutants are emitted during the performance of a hydraulic fracturing job. However, emissions are regulated by the Environmental Protection Agency (EPA) under the authority of the Clean Air Act (CAA). States may implement the federal regulations, and in some cases, state and local governments impose more stringent restrictions on air emissions. Impacts on air emissions related directly to hydraulic fracturing include:

- Truck traffic from water hauling and equipment mobilization can release emissions based on consumption of fuel and the potential to increase dust in air (Nguyen, 2010). Mitigation efforts include locating source water close to well sites, temporary or permanent pipelines, and water recycling. Converting trucks from diesel to natural gas could also serve to reduce transport emissions.

- Diesel engine power sources are a point of emissions. Historically emissions have been reduced 75% and are scheduled to be reduced an additional 90% from today's standards in the next 5-6 years . (40CFR80, 2010; 40CFR89, 2010). Mitigation efforts include:

  - Smaller, more powerful turbine engines being used to power the blenders, pumps and other equipment in hydraulic fracturing operations, which reduce the amount of emissions (Gosnell, 2011).

  - Storage of fracturing sand in upright storage containers atop the blenders that are operated with solar-powered systems, eliminating diesel engines (Clanton, 2010).

  - Alternative fuel/power supplies that may be available in the future and may range from natural gas powered to fuel cells, although the potential of such alternatives is currently a goal and much research will be required to make this a reality.

- Emissions during post-stimulation activities can occur from production of the well. This may not be directly linked with hydraulic fracturing but may happen during the time of recovery of fracturing fluids. Release of natural gas may occur during this time and until the well is placed on production. Monitoring is performed to assure no violations of federal air quality standards for ozone occur (40CFR50, 2010). Mitigation efforts include development of "green completions" where the natural gas is separated and placed in pipelines for sale when available (EPA, 2004).

- Storage of post-hydraulic fracturing produced water in surface pits may release chemicals and other light hydrocarbons dissolved in the liquids. Mitigation efforts have included the use of closed-loop systems for handling produced water. In some states and urban areas this may be a regulatory requirement.

Minimizing air emissions is also beneficial to industry. Capturing methane emissions generates additional revenue for industry, increases operational efficiency, and conserves natural gas while reducing environmental impacts (EPA, 2011a). The Natural Gas STAR program is a voluntary partnership to implement methane-reducing technologies and practices in all facets of oil and gas development, including hydraulic fracturing. Through this collaboration, industry has a suite of comprehensive technological information and practices that have been used successfully to reduce emissions in hydraulic fracturing.

B. Water Sourcing

Water used in hydraulic fracturing can come from surface water, groundwater and reused water from other sources, such as previous hydraulic fracturing operations (Veil, 2010). There are concerns that when ground or surface water is used in hydraulic fracturing and disposed of in underground injection wells, it is considered to be consumptively lost to the water lifecycle (Penn State, 2010). The following provides information on the individual water sourcing options.

(1) Surface Water Sourcing

The use of surface water for hydraulic fracturing is affected by several factors, including regional precipitation, seasonal flow, and distance from a stream or lake. Some areas have abundant precipitation, theoretically making streams, rivers, and lakes viable water sources (Arthur et al., 2010). However, even in areas with abundant rainfall, water availability may be affected by seasonally low stream flows or drought. In addition, the distance from the water source to the well location can hinder the source's practicality because of the high cost of transportation. Thus, even in basins with abundant water supplies, operators often need to have multiple water sources to ensure an adequate supply. Cumulative impacts from surface water withdrawals for hydraulic fracturing can include:

- Impacts to stream flow, fish and aquatic organism impacts, wetland and terrestrial habitats and water quality degradation can occur when runoff and other sources are not adequately diluted or become concentrated due to the reduction in water availability (New York DEC, 2009). Mitigation efforts include selectively locating the withdrawal location, demonstrating that sufficient flow capacity is available before initiating withdrawals, and capturing water during high surface flows and storing until needed (GWPC-ALL, 2009).

- Impacts can occur to municipal and industrial water supplies if water availability is decreased (Arthur et al., 2010). Impacts can be mitigated by demonstrating that sufficient flow capacity is available before initiating withdrawals. This may be managed by state/local agencies managing permits to withdrawal.

- Water that is used for hydraulic fracturing operations is often considered consumptively lost to the hydrological system. Mitigation efforts include water recycling and reuse (Penn State, 2010).

(2) Groundwater Sourcing

The primary concern associated with groundwater withdrawals for hydraulic fracturing is the potential for aquifer drawdown or depletion, which could impact other uses such as public and private water supply wells (NY DEC, 2009). Groundwater withdrawals may not have a significant impact individually; however, multiple withdrawals in concentrated areas in excess of the recharge rate could decrease the water table or deplete resources that are currently used by other sources. Additional impacts from groundwater withdrawal include:

- Salt water intrusion
- Contamination from surface water
- Lower water levels in surface water bodies, streams and wetlands (Alberta Wilderness Association)
- Release of free gas (e.g., in coal bed aquifers, if the water head is significantly reduced and natural gas exists, the natural gas may be released and, if not produced, migrate and cause concerns over groundwater contamination) (Alberta Wilderness Association)

Mitigation efforts require monitoring of groundwater levels to assure that safe levels are maintained.

(3) Produced Water Sourcing

Typically some of the fracturing fluid remains in the formation after hydraulic fracture operations are complete. The amount recovered varies between basins and plays, and may range from less than 30% to more than 70% of the original injected volume (GWPC-ALL, 2009). The remaining water may not be recovered through production of the well. The use of produced water is a directly applicable mitigation procedure to lessen the impacts of water sourcing when hydraulic fracturing a well. Treatment of produced water, which would otherwise be discarded, can allow water to be used in hydraulic fracturing operations, reducing the volume of new water needed from alternative sources. Use of produced water also reduces the impacts associated with disposal of the water by alternative methods.

When necessary, produced water can be blended with fresh water. This process dilutes the produced water constituents to an acceptable concentration range for use in fracture operations. This mixing can make produced water a viable source of water for some of the water needed for hydraulic fracturing.

(4) Produced Water Management Challenges and Concerns

States, local governments, and operators seek to manage produced water from a well after hydraulic fracturing in a way that protects surface and groundwater resources and, if possible, reduces future demands for fresh water (GWPC-ALL, 2009). Management of produced water is typically performed through one of the following:

- Underground injection when favorable geology is present.
- Treatment and discharge or use (can occur onsite or at municipal waste water treatment plants or commercial treatment facilities) – When produced water is treated, a concentrated brine solution remains that must undergo disposal.
- Recycling – see Produced Water Sourcing above

For produced water storage, the following mitigation measures can be implemented to alleviate potential groundwater impacts:

- Use above ground tanks in lieu of pits for produced water storage whenever possible
- Line Pits, when used, sometimes with multiple liners and leak detection systems between the liners
- Groundwater monitoring wells if a pit or impoundment is utilized for a longer duration.
- Construct and design impoundments to provide structural integrity (API, 2011).

C. Surface Disturbances

A pad for a well that will undergo hydraulic fracturing must be of sufficient size to provide storage of the chemicals and equipment needed to perform the hydraulic fracturing stimulation. Operators may construct surface water impoundments to store fresh water for fracturing and impoundments may also be constructed to temporarily hold produced water before transportation to a disposal site. In some situations, underground pipelines may be constructed to transport fresh water from a centralized impoundment to the wellsite.

Surface disturbances are lessened through the use of horizontal wells and the ability to use hydraulic fracturing for completion. When developing oil and gas resources in this manner, fewer wells are drilled to effectively produce the resource and therefore reduce the amount of surface disturbance. In addition, when multi-well pads are used in the development, surface disturbances are further lessened (GWPC-ALL, 2009). Use of horizontal wells and hydraulic fracturing of those wells is a direct mitigation measure to lessen the impacts of the development of the resource. Not only are multi-well pads being developed but centralized fracturing facilities are also being developed in certain areas to service these multi-well pads, greatly reducing the surface disturbance associated with hydraulic fracturing of multiple wells (NETL, 2006).

The surface disturbances associated with hydraulic fracturing are typically short term. Once a well or well pad has been drilled and completed, the portions of the well pad that are no longer needed during the production phase of the well are reclaimed. Once a well reaches its economic limit and production is no longer viable, the well is plugged and the remaining surface disturbances are reclaimed and restored.

D. Biological Impacts

The development of a resource utilizing horizontal wells, drilled from multi-well pads, and hydraulic fracturing minimizes the number of wells and surface disturbance needed to develop a resource fully, which in turn minimizes the biological impacts. Research has documented that activities associated with oil and gas production can affect wildlife and its habitat, as can any other human activity (Bromley, 1985). State regulations and, in some cases, local ordinances include stipulations dictating operational restrictions to provide added protection for wildlife or sensitive resources. Some mitigation measures include placing restrictions on development, instituting more stringent permitting requirements, and establishing restrictions on when operations that may affect threatened or endangered species can be conducted. Scheduling hydraulic fracturing procedures to coincide with these permit requirements may be necessary and should be planned for in field development.

E. Vibration

Recent seismic events in areas with oil and gas development have caused scientists to wonder if there is a connection to industry activities. These events have been focused attention on, not hydraulic fracturing (Sider, 2010; Frohlich et al., 2010). Use of disposal wells is necessary for the management of produced water from hydraulically fractured wells in certain areas. To mitigate the possible effects of seismic events, the geologic structure surrounding the injection wells needs to be thoroughly investigated and injection rates monitored. Ongoing studies to determine the connection between underground injection and seismic activity should provide more comprehensive information.

F. Noise

The noise impacts associated with hydraulic fracturing include:

- Vehicle traffic noise – Mitigation measures include reusing produced water and transporting water via pipeline from a centralized water storage impoundment or water source

- Fluid handling and pumping noise – Mitigation measures include maximizing distance from human and wildlife receptors, restricting timing of operations, directing noise equipment away from receptors, and utilizing artificial or natural sound barriers.

G. Visual Impacts

The visual impacts associated with hydraulic fracturing are primarily due to the large number of trucks and equipment necessary to perform the fracture stimulation and should be considered short-term in relationship to the life of the well. Operators should address visual impacts during the design phase of the well and pad location. Many states have setback requirements from occupied residences, property lines, and road and directional lighting requirements, which minimizes the visual impacts associated with hydraulic fracturing operations. Operators in some areas of the country are testing the use of centralized fracture facilities, which would minimize the visual impacts associated with development of multiple wells (NETL, 2006).

H. Community Impacts

Community impacts associated with hydraulic fracturing include short-term increases in traffic volume, road damage, dust and noise. Mitigation measures include

- Using avoidance practices and adjusting schedules to alleviate traffic congestions
- Water unpaved roads to reduce dust
- Installation of sound barriers
- Installation of temporary pipelines to transport water from centralized water sources and to transfer produced water to disposal facilities
- Road maintenance and repair agreements.

ECONOMIC IMPACTS (POSITIVE AND NEGATIVE)

The economic benefits of hydraulic fracturing to the industry are many. The technology has a positive impact on the rate of return on investment in a well. Hydraulic fracturing creates a permeable channel through which hydrocarbons travel more freely, increasing production rates and total recovery from the well. This helps to better manage the resource as hydraulic fracturing can help the operator to effectively produce the reservoir with fewer wells and less overall expense. In addition to its use during the initial completion of a well, hydraulic fracturing can also be improve production rates and allow continued operation at economically viable levels when a well has declined to near its economic limit. The continued production beyond the previously established economic limit allows operators to recoup the costs associated with hydraulic fracturing.

Hydraulic fracturing is not only used to increase and expedite the recovery of resources that may be extracted without its use, it also provides a means to produce oil and natural gas that is trapped in rock beds that would otherwise be unattainable (Energy in Depth, 2010). If future regulations halted the use of hydraulic fracturing in domestic oil and gas operations, it is estimated that the federal government alone would lose $4 billion in revenue, state governments would lose $785 million in taxes and the direct and indirect jobs that would be lost as a result would be detrimental to the economy. An estimated 183,000 barrels of oil per day and 425 billion cubic feet of natural gas would be lost every year (Energy in Depth, 2010).

Shale gas is a specific resource that can be profitably recovered only through the use of hydraulic fracturing. Hydraulic fracturing has helped to create a boom in the development of shale gas resources across the county. Shale gas now offers the United States more than a 100-year supply of natural gas (Hayes, 2010). In the Barnett shale, an area commercialized by hydraulic fracturing, the total effects of development include $8.2 billion in annual output, $2.4 billion in annual retail sales, and 83,823 permanent jobs (IOGANY, 2011). An American Petroleum Institute (API) study conducted in 2009 stated that expanded hydraulic fracturing has added approximately 57,000 direct and indirect jobs in Pennsylvania and five other states with Marcellus shale development (Considine, 2010). Continued development of the Marcellus shale could lead to upwards of 280,000 new jobs with additional tax revenues of approximately $6 billion (Considine, 2010).

Hydraulic fracturing is expensive, often representing a large percentage of the drilling and completion costs for a well. For the Marcellus shale, drilling costs in 2009 averaged $1.5 million per well while well completion costs averaged $2 million per well (Schweitzer and Bilgesu, 2010). The costs of hydraulic fracture stimulations vary depending on the size and type of the stimulation and can range from $100,000/stage to $175,000 per stage (with the number of stages typically ranging from 8 to 15, but possibly going as high as 20 or more), depending on the length of the completion interval (Schweitzer and Bilgesu, 2010). A few elements that impact the costs of hydraulic fracture stimulation and operational costs of a well include:

- Additives used
- Water purchase costs
- Water Transportation Costs
- Produced water and disposal costs (including water treatment costs).

Water sourcing, produced water management and disposal expenses directly related to hydraulic fracturing vary depending on the management alternatives used or available in the play. The cost to transport water from the source to the well location to use in hydraulic fracturing can range from $0.10/barrel to $2/barrel depending primarily on the distance between the source and the well location (Vidic, 2010). Transporting produced water from the well to treatment or disposal sites can be even more costly. In the Marcellus region, injection of produced water is limited due to geological constraints, forcing some operators to transport produced water hundreds of miles to commercial disposal facilities.

Treatment and recycling of produced water can decrease the costs and alleviate the challenges and environmental impacts associated with water sourcing, but the process does not come without a cost. Devon Energy reports that treatment and recycling costs approximately 40% more than traditional disposal methods (Devon Energy, 2008). Mobile treatment costs can reach up to $7.37 per barrel (Atlas Energy, 2010). One company reports the cost of recycling water in the Barnett Shale, including transportation and disposal of the concentrate, is $4.43/barrel compared to $2 to $2.50 per barrel for disposal into an injection well (Basin Oil & Gas Magazine, 2010). Those costs must be contrasted and compared regionally to determine the best economic options for individual developments.

There are also indirect economic benefits that have transpired from the increased natural gas development in the country. The increased availability of natural gas has allowed plastics and petrochemicals to remain competitive in the global market. Natural gas provides ethane feedstock, which is converted into ethylene, a primary component of polyethylene and PVC (DOE, 2006).

INNOVATION AND FUTURE USE

The current status of hydraulic fracturing technology is continually evolving to address both public concerns and the needs of the industry. The ability to fully address all current innovation and new research being developed for hydraulic fracturing is beyond the current scope of this report. The information presented below provides a broad view of the advancements being performed and believed future use in the individual segments of hydraulic fracturing technologies.

Each hydraulic fracture job performed provides new information and insight into the process and the resource play where applied. It should be noted that a major focus on current technological research and development applies to the resources of Shale Gas and Shale Oil. Research in these resource plays is expected to yield beneficial and more efficient use of hydraulic fracturing technology in other resource plays in the future.

A. Use of renewable energy sources

Halliburton has released a plan to redesign the storage containers that hold fracturing sand from giant trailer-like containers that are driven by diesel engines, hydraulics, and conveyors to upright gravity feed containers atop the blenders that operate using a solar powered battery operating system in lieu of diesel engines (Halliburton, 2009a).

B. Technology from Urban Development

Where oil and gas development has intersected with urban settings, regulators and industry have evaluated methods to alleviate environmental impacts and interference with community and commercial activity (API, 2011). For example, development of the Barnett shale in the Dallas/Fort Worth (DFW) area and the DFW Airport has led to multiple ordinances and lease requirements specifically pertaining to oil and gas development and hydraulic fracturing.

Noise impacts are one of the most common issues associated with hydraulic fracturing in urbanized areas. Trucks transport equipment, water for hydraulic fracturing, proppant, produced water, and fracture tanks. When hydraulic fracturing is coupled with horizontal drilling, there are a reduced number of well sites that generate noise and operators have greater flexibility to locate the well in a location that would minimize noise impacts and community impacts.

Another tactic to minimize noise and traffic congestion is to blend acids "on-the-fly" when used as part of the hydraulic fracturing operation (Halliburton, 2009b). Acid is delivered to the well site in concentrated form, rather than diluting prior to transportation. This method reduces the waste and the air emissions from the reduced number of tanks and truck trips that would otherwise be required.

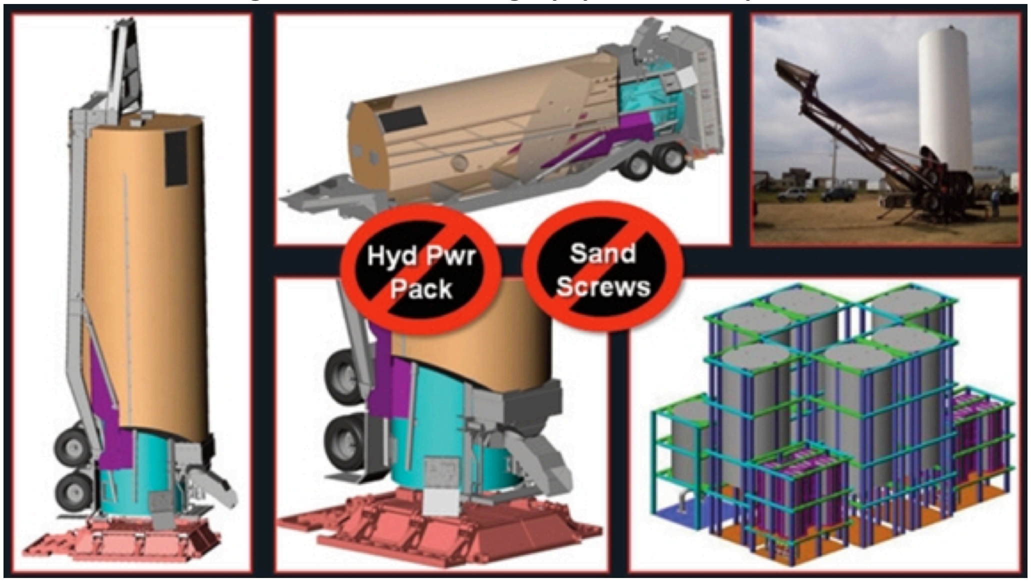
Noise analyses are becoming more prolific as development breaches urban areas (Colorado OGCC, 2005). State and federal regulations sometimes require an analysis be conducted prior to initiation of a new project, and in other cases, operators perform the analysis as part of community outreach programs and as a defense against potential litigation. The results of the analyses can be used to determine effective noise abatement strategies to minimize the impacts associated with hydraulic fracturing in urban areas.

Lighting issues are also a concern in urbanized areas. Operators use tempered fluorescent bulbs and directional lighting to minimize the impacts to neighbors in the vicinity (Mocarsky, 2010).

C. Technology to Limit Surface Impacts

The surface impact of hydraulic fracturing operations varies depending on operational equipment and needs. Service companies are now experimenting with automated equipment that can be run from remote operations centers, which would minimize the number of pumping engines that would be required on the location. Service companies have also looked into building more reliable pumping engines, which would alleviate the need to have multiple backup units on site (Clanton, 2010). Development of new wellsite equipment can help to address impacts. Figure 3 shows new equipment developed to lessen surface impacts through the use of new sand handling equipment.

Figure 3: Sand Handling Equipment – Footprint



Source: Halliburton Energy Services, Inc., "Well Stimulation Technology" (January 2011).

Centralized produced water pits are often replaced with contained tanks, which minimize the air emissions and potential for leaks and breaches of the impoundments. In addition, drilling rigs and hydraulic fracturing equipment are sometimes placed on raised platforms to alleviate surface impacts and lined containment facilities are used to catch any spilled fluids that could leach into the soil (Lustgarten, 2008).

Centralized hydraulic fracturing pads are another technique being explored in some basins to minimize surface impacts associated with hydraulic fracturing (BLM, 2009). Hard line fracturing pipes are run from the centralized facility to the wellsite, often running over a mile. As a result, water hauling truck trips are reduced and dust and tailpipe emissions are decreased. In Colorado, one company has hydraulically fractured as many as 140 wells from a single centralized location, some almost 3 miles away (Pickett, 2010). This type of facility also encourages recycling produced water for subsequent hydraulic fracturing operations. Due to the system configuration, water can be treated and prepared for the next fracturing stage while the first stage of the stimulation is going on. On a multi-well pad, this can reduce truck trips by up to 90 percent (Pickett, 2010).

D. Fluids/Chemicals

The service companies associated with hydraulic fracturing chemicals have been developing and improving green chemicals for development of off-shore resources for years (Devine et al, 2003). These companies are now bringing some of these chemicals as well as new chemicals to market here in the United States (BJ Services, 2008). These chemicals are designed to effectively achieve the needed task during the fracture treatment and then revert to an inert or stable end product. Some chemicals like organics acids react in the subsurface environment and are altered to inert salts; other chemicals like aqueous biomass control agents are designed to react quickly and break down into inert compounds (Blauch, 2010). In developing these chemicals the goal is to reduce the potential hazardous at the surface (eliminating possible exposure dangers that could cause diseases), in the subsurface, and in the future from any potential exposure that may occur.

Not only are service companies focusing on creating more green products as injection chemicals, they are focusing on unique ways to manage injection fluids. Operators and service companies are working together to develop closed-loop hydraulic fracturing systems which result in full containment of all chemicals used throughout the hydraulic fracturing process. Full containment systems reduce the chances of accidental discharges by spills, and ensure that all produced water is captured and maintained without discharge to the surface.

In addition, other advancements are occurring that can assist in the elimination or reduction of chemicals used for a job. Use of ultraviolet light to replace biocides is an example (Figure 4). This is a mechanical means of addressing what chemicals did in the past.

Figure 4: Tool That Uses Ultraviolet Light to Act as a Control for Bacteria

Source: Halliburton Energy Services, Inc., "Well Stimulation Technology" (January 2011).

While minimizing the risks associated with the chemical additives used is essential, it is worth noting that eliminating all chemical additives in hydraulic fracturing could create greater environmental risks than those associated with the use of chemicals (Bosch, 2011). The successful use of chemical additives allows an operator to maintain control over the biology and chemistry of the source water, which minimizes the overall environmental risks while maximizing hydrocarbon production. While the use of green chemical alternatives is a viable tool for risk mitigation, analysis of the full lifecycle of the constituents will capture the effectiveness, the full effect of concentration ranges necessary to achieve performance targets, and the positive and negative residual effects from an environmental perspective.

E. Proppants

While sand has been the most popular proppant for hydraulic fracturing in oil and gas operations due to its availability and low cost, other options are being developed. Ceramic proppants have uniformly sized and shaped grains, which provide maximum porosity and improved production of oil and gas in a variety of different reservoir types (Palisch, et al., 2007). Development of new proppants that also pose less risk to the health and safety of those handling the materials at the well site is a goal. This could help to eliminate such exposure to silica which has been linked to causing silicosis (OSHA, 2002).

Another new innovation in proppants is a high-strength spherical proppant with integrated proppant flow back control. Changing the geometry of the proppant has been proven to improve the conductivity beyond what is attainable with spherical proppants (McDaniel et al., 2010).

Non-radioactive traceable proppants are also being used to help identify proppant coverage and fracture height in a wide variety of wells (SPE, 2010). The technology was first developed for offshore completions to identify failures on an offshore platform (Palisch, et al., 2007). The naturally occurring chemical markers are added to the proppant during manufacturing. It is safe and environmentally responsible and requires no special disposal of the flowed back proppant (Palisch, et al., 2007).

Light weight proppants, another new product, reduce the gel viscosity needed, which significantly reduces gel costs. In addition, proppant flowback is virtually eliminated. (Posey and Strickland, 2005).

F. Equipment Advancement

Just as fluid chemistries and additives vary by well and basin, so does the caliber of equipment that is needed to successfully perform the hydraulic fracturing stimulation. For example, offshore wells are typically stimulated under higher temperatures and pressures than onshore wells (Halliburton, 2009c). As a result, the equipment must be designed to meet the challenging bottom hole conditions.

The equipment that is used in fracturing has been modernized over the years to accommodate the different technologies, such as high volume hydraulic fracturing. Fracturing pumps can now accommodate a wide range of pressures and rates, and some even have wireless remote controls and wireless monitoring of rates and pressures (Trican Well Service, 2011). Data acquisition vans can monitor several dozen fracturing pumps and associated equipment simultaneously. Manifolds are designed to withstand higher pumping rates and pressures. Even produced water treatment units have adapted and become mobilized. Additional equipment advances, such as the Advance Dry Polymer Blender (ADP) shown in Figure 5, demonstrate the same continuous mixing on site the industry has come to expect while reducing the environmental footprint. Previous technology required gelling agents (guar powder) to be blended in oil-based carrier fluid, like mineral oil, that is then added to the water used for fracturing on site. The ADP eliminates this requirement and mixes the gelling agent (in a dry powder form) with the water used for hydraulic fracturing on site. This mechanical success eliminates the oil based liquid from the process.

Figure 5: ADP Blender

Source: Halliburton Energy Services, Inc., "Well Stimulation Technology" (January 2011).

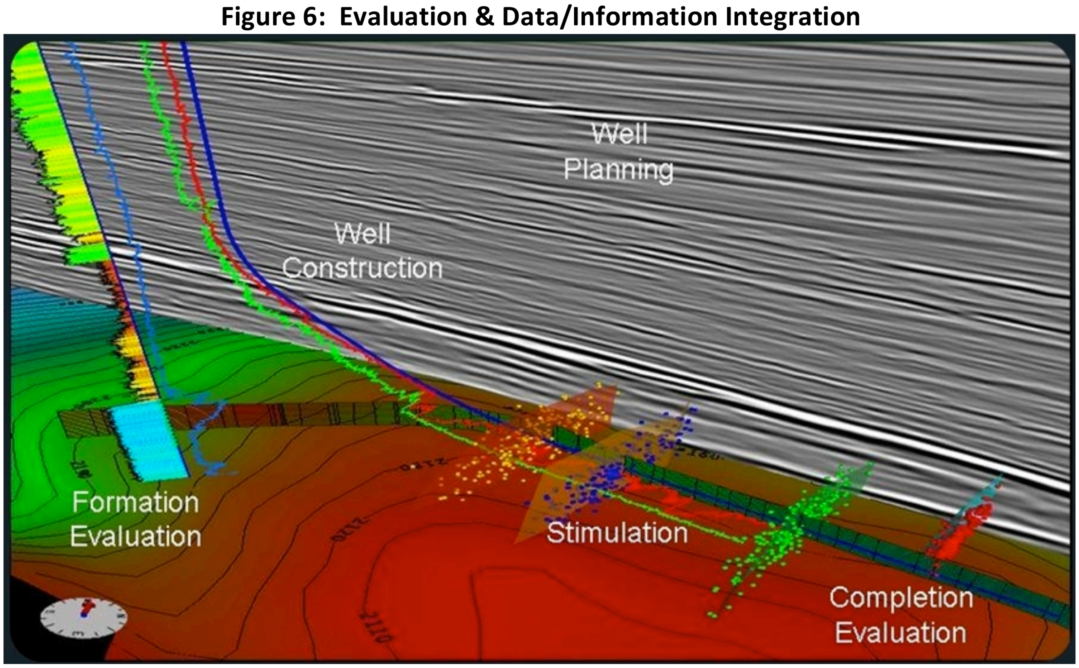
G. Design

Design technology has advanced greatly over time, and will continue to advance into the future. Today, design of hydraulic fracturing jobs may take into account not only the individual well stimulation, but also the production of the whole reservoir and interaction between wells.

Detailed design of any hydraulic fracturing job is critical to the success of the job. Upfront design uses past performance to identify why a job has been successful or not, and then identifies how to capitalize on that past performance for the next job. In the design of a hydraulic fracturing job, the fracturing engineer gathers information on the reservoir to be fractured, and uses that information to select, optimize and place the stimulations performed to economically produce the reservoir (Rich and Ammerman, 2010; Sondergeld et al., 2010; King, 2010). Many data sources are considered when designing a hydraulic fracturing job and may include 3D seismic, geologic mapping, core analysis, drilling logs, open hole logs. Of particular interest will be previous stimulation jobs in the reservoir and how those stimulations have performed relative to the production of hydraulic fracturing fluids and the production of the resource (King, 2010). Integration of these multiple streams of information using multi-disciplinary techniques is necessary to the design of hydraulic fracturing jobs (see Figure 6 for an example).

Design of the next job, in a particular or similar reservoir, may include the integration of new techniques or new products specifically designed to address a shortcoming identified from of a previous hydraulic fracturing job performed or new requirements such as regulations or use of green chemicals. These new techniques or products will often be modeled during the design phase. Through the use of predictive computer models and the data collected on the reservoir, its performance and hydraulic fracturing components properties, each particular stage of a hydraulic fracturing job can be tweaked and adjusted to provide what is expected to be the most favorable outcome for the production of the resource. Each new design performed for the next hydraulic

Figure 6: Evaluation & Data/Information Integration



Source: Halliburton Energy Services, Inc., "Well Stimulation Technology" (January 2011).

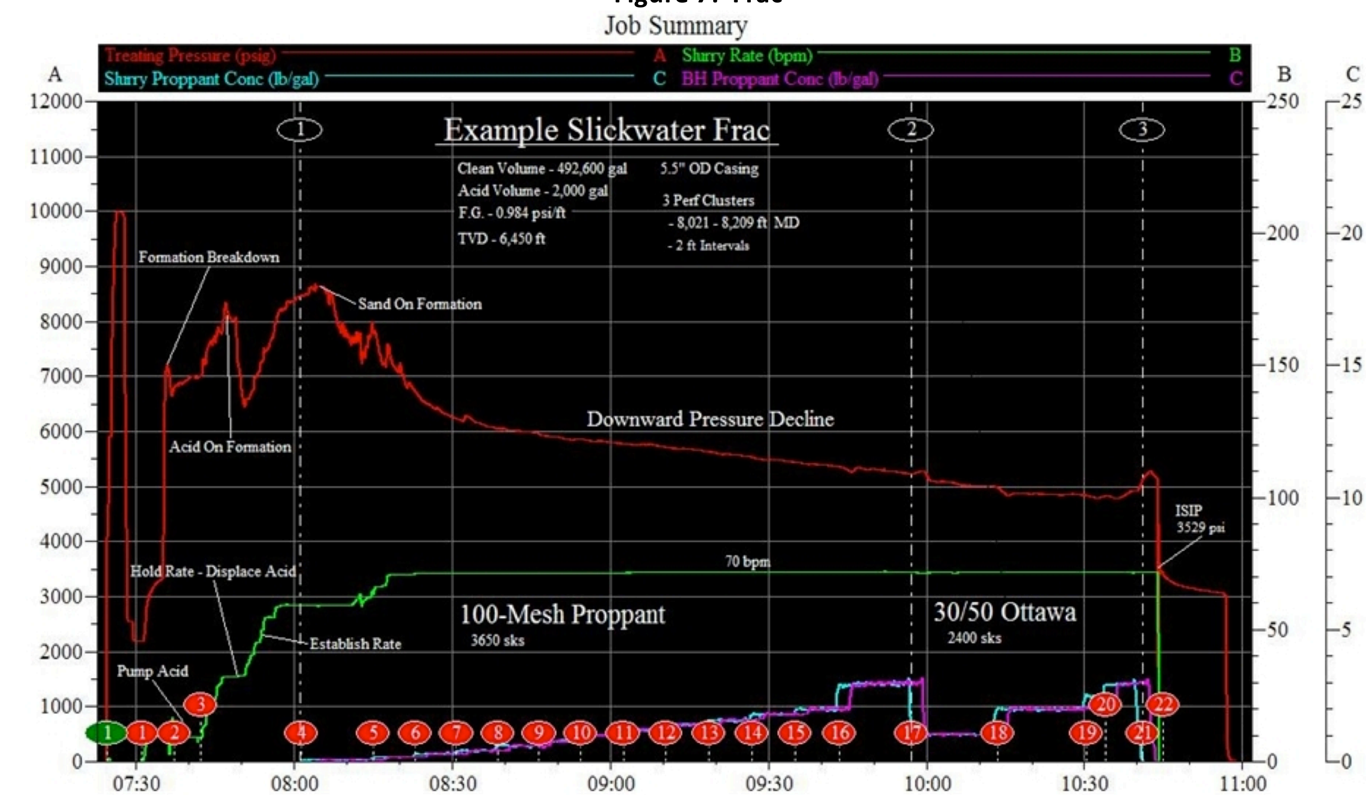
fracturing job focuses on better addressing resource recovery and reduction of costs relative to the economics of the well and the resource being produced.

H. Onsite Real-time Job Management

The technology to monitor and manage onsite hydraulic fracturing jobs has increased greatly over the years. Today sophisticated computer systems are used in technical monitoring vehicles for the fracturing service supervisor, engineers, pump operators and company representative. In these vehicles, activities associated with the fracture treatment are monitored and coordinated, including all treatment pressures, chemicals, proppant density, fluid velocity, and pressures. These vehicles are also where all data is recorded and reviewed. Within the vehicle the entire fracture stimulation is tracked for each stage that is performed.

During this onsite job management, stimulations are monitored continuously by operators and service companies to evaluate and document the events occurring during the treatments (Figure 7). Monitoring of fracture treatments includes tracking the process with wellhead and downhole pressures, using microseismic technology to estimate the orientation and approximate sizes of induced fractures, monitoring pumping rates, measuring fracturing fluid slurry density, tracking volumes for additives, tracking volumes of water, and ensuring that equipment is functioning properly. Monitoring and tracking of this data helps the onsite personnel assess if the hydraulic fracturing job is performing as expected and also provides them the ability to address changes in the job as necessary to assure a successful well completion. During a typical hydraulic fracturing event for a horizontal well, there may be more than 30 service company representatives on site performing and monitoring the stimulation as well as additional staff from the operator and

Figure 7: Frac



Optimization – Monitor and Adjust

perhaps the state oil & gas agency (Arthur et al., 2008).

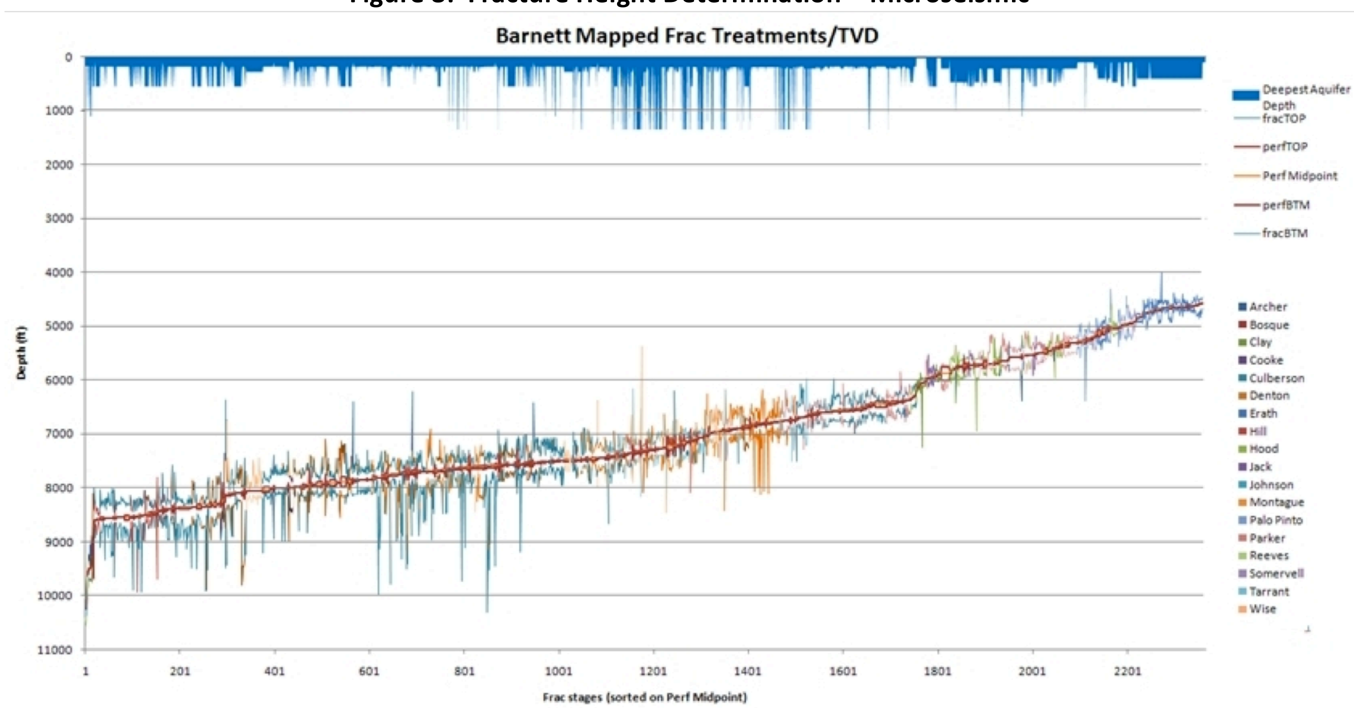
Improvement of onsite monitoring and relating the activities occurring onsite to the design and predictive models will continue in the future. By continuing to refine the monitoring of jobs and to increase the quality of the data collected and analyzed, operators can improve future stimulation treatments.

I. Measurement of Success

After completion of the hydraulic fracturing job, the information collected during the performance of a job is used to do an after action assessment on the job performed. This helps to identify the potential for improvement and to identify the successes that have occurred. In addition to the information collected during the performance of the job, production of fluids (oil, gas and water) is measured and used to verify the success of the job. This post-completion measurement of the success of the hydraulic fracturing job is paramount in helping to analyze the success of not only the job performed but future job performance.

The measurement of success through the use of measurement technology, such as microseismic, provides a means to determine the location and size of fractures developed. This provides a means to assess success of the fracture job performed. Figure 8 presents the distance between the fracture height and the water table in fracture treatments performed in the Barnett Shale. As shown below, the distance between the fractures created and the water table is thousands of feet.

Figure 8: Fracture Height Determination – Microseismic

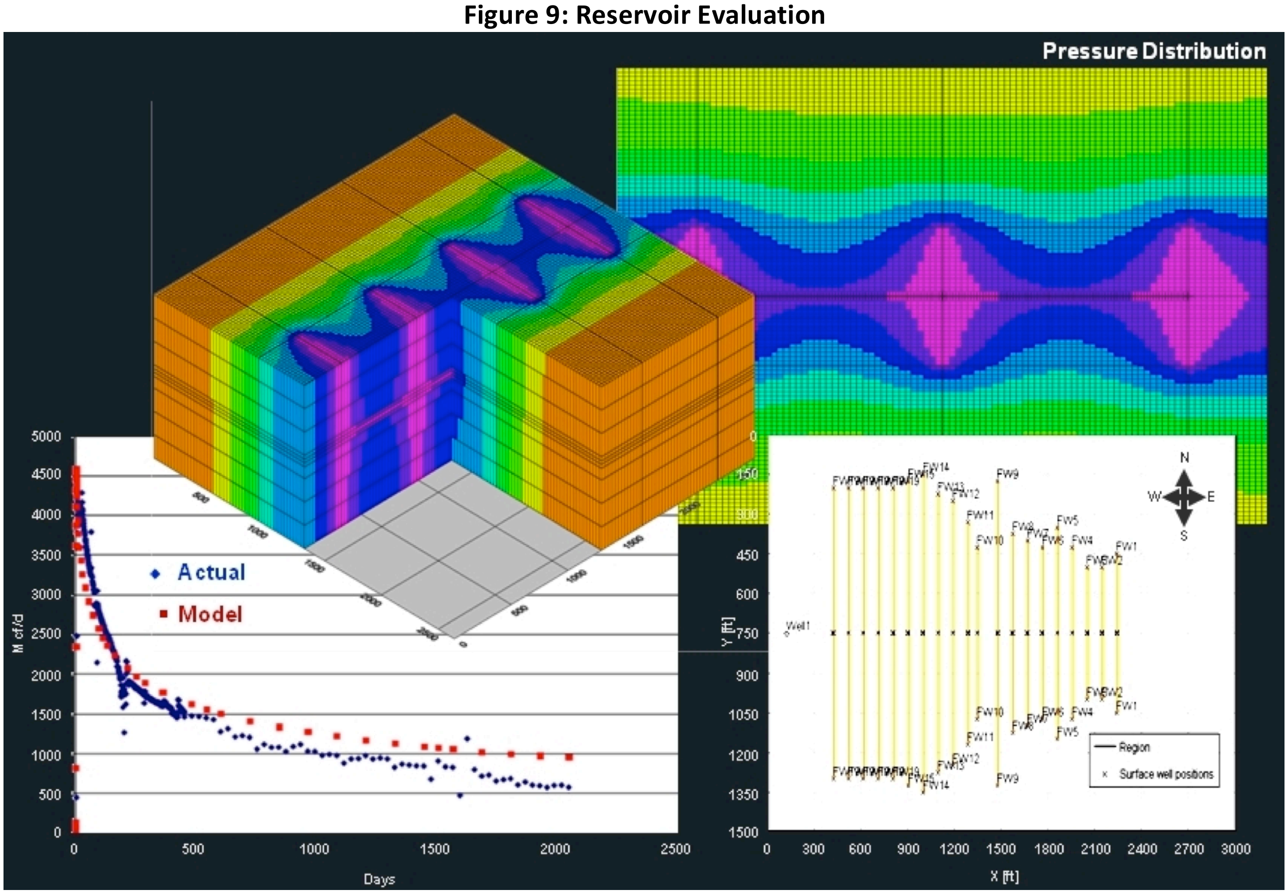


Source: Kevin Fisher, "Data Confirm Safety of Well Fracturing," *The American Oil & Gas Reporter* (July 2010).

Continued refinement of the hydraulic fracturing process occurs as operators analyze more resource-specific data collected. As more data is collected and analyzed, the engineers can incorporate the information learned to design future jobs and address such factors as more optimized fracture patterns within the target formation, better placement of proppant, and better control of in-zone fracture growth. With better measuring and understanding the reasons for success from a job, increased resource recovery and decreased costs can occur for future jobs (Bybee, 2007 and Ketter et al , 2006). For example, the refinement of the hydraulic fracturing process was a necessary step in the success of the Barnett Shale as development moved away from the core area of the Barnett; this was accomplished because of the ability to measure the success of the jobs performed (Parshall, 2008). As a result, fracturing processes have been refined as the technology has evolved (Arthur et al., 2008).

The continued measure of success is further implemented in the modeling of the jobs performed to match the information collected (Figure 9). These models can then be refined further to help in the future design and implementation of additional hydraulic fracturing in the resource area. Not only does this modeling analysis help in a specific resource area but it also helps to refine the models used to predict hydraulic fracturing success. This technology can then be applied to future resource areas, providing the ability to more rapidly increase success rates in a new resource area and therefore reducing future costs and environmental impacts. This is apparent through the lessons learned from shale gas fracturing in the Barnett shale and the development of slickwater fracturing and its translation to other shale resource plays.

Figure 9: Reservoir Evaluation



Source: Halliburton Energy Services, Inc., "Well Stimulation Technology" (January 2011).

J. Groundwater Protection

Concern over groundwater protection is one of the most prolific public concerns that has been expressed over the last decade. State regulatory programs place a strong emphasis on casing design and protection of fresh groundwater resources. Current well construction requirements consist of installing multiple layers of protective steel casing and cement that are specifically designed and installed to protect fresh water aquifers and to ensure that the producing zone is isolated from overlying formations. Conductor and surface casing strings are set in the borehole and cemented in place. In some cases, additional casing strings are also set and cemented.

A variety of checks are used to ensure that the desired isolation of each zone is occurring including some that ensure that the casing used has sufficient strength and that the cement has properly bonded to the casing. These checks may include acoustic cement bond logs and pressure testing to ensure the mechanical integrity of casings. Additionally, state oil and gas regulatory agencies often specify the required depth of protective casings and regulate the time that is required for cement to set prior to additional drilling. These requirements are typically based on regional conditions.

Design and modeling cannot always anticipate the unpredicted events that can occur over the life of the wellbore, such as overpressuring, unanticipated formation subsidence, or tectonic activity. As a result, cement designs frequently incorporate certain additives that can overcome unforeseen events, such as the presence of flowing gas or crude oil (Hunter et al, 2007). A cement sheath that can react in the event of a failure and repair itself automatically, sealing the flow pathways before intervention would be necessary, has been developed. The repair ability is not limited to a single incident. If cement sheath is damaged again, the technology will self repair on multiple, independent occasions (Schlumberger, 2011b).

During the fracturing treatment high pressure water and proppant is pumped down the well to fracture the formation. This may be the only time during the life of a well that the casing is subjected to high pressure. To minimize the impact on the casing, a “frac string” of pipe is run into the well to protect the casing during the fracturing process. This frac string is designed to withstand the high pressure during the fracture treatment and is removed after the job is complete. In this way the casing is not subject to the high pressure of the fracture treatment and the cement outside the well is not impacted by the fracture treatment (API, 2009).

K. Water Management

The concerns of water management and water use for hydraulic fracturing have grown significantly in the last five years as a result of the expanding development of shale gas plays and the completion techniques necessary to develop shale gas into a viable economic resource. The high volume hydraulic fracturing (HVHF) techniques developed in the Barnett shale are translatable to other resource areas across the U.S., and, as such, water concerns and water management issues are developing in areas that may not have traditionally been exposed to oil and gas development. Although the natural gas industry is expected to increase total water usage by less than 1.5% in each shale gas area, the usage is nonetheless “incremental” and presents an additional challenge (Chesapeake, 2010). The largest water users are municipalities (public water supply), power generation, industrial users and agriculture. Water used for hydraulic fracturing differs from other usages because it is temporary, occurring only during the drilling and completion phases of each well. Use of this water does not represent a long-term commitment of the resource. Through the use of evolving design, monitoring and success measurement in hydraulic fracturing a better understanding of the use of the water in HVHF activities and its ultimate fate is being explored. Addressing the concerns expressed for water management are critical for the success of the use of hydraulic fracturing and the development of resource plays. The following presents a summary of various aspects of water management being addressed through innovative ways:

(1) Water Sourcing

HVHF will require the continued development of additional sources of water or the development of technologies that minimize the volumes of water that is needed to successfully hydraulic fracture a well. Migration of the development activities into new areas and the evolution of multi-state watershed-based regulatory agencies which oversee consumptive and non-consumptive water use within these basins have created this need for industry to evolve water sourcing practices (Arthur et al., 2010). This need for large volumes of water has led to operators evaluating new areas of water sourcing, from recycling the water their development operations already produced to tapping other industries for water sources (Rimassa et al., 2009b).

As shale gas plays mature, there appears to be a migration toward finding alternative carrier fluids to facilitate the fracturing of the lower permeability shale formations. Development of engineered proppants in the future may decrease the volume of fluid needed to fracture and place the anthropogenic permeability needed to produce these tight formations. Slurries which use nitrogen or other gases can be used to help carry proppants into the formation.

A variety of material can be used to replace water as a fracturing fluid, including foam treatments utilizing carbon dioxide and/or nitrogen or using a hydrocarbon based-material like Liquefied Petroleum Gas (LPG). Foam treatments and some hydrocarbon-based fluids have been around for years and have been utilized successfully in a variety of applications (Loree and Nevison, 2010). Recently, LPG is being used to replace water as a fracturing fluid in some hydraulic fracturing treatments in the Western Canadian Sedimentary Basin (WCSB) and expansion of applications is being evaluated to other geographical regions (GASFRAC Energy Services, 2007). All of these options can reduce and alleviate water requirements as well as the challenges of produced water disposal. In excess of 90% of the LPG load fluid has been recovered in all applications directly into sales lines.

Recycling of produced water and use of other alternative sources of water is expected to be a critical component of future development activities of oil and gas resources. Operators and service companies are working to develop fracture chemicals, fracturing strategies using fewer chemicals, and treatment strategies that facilitate the re-use of produced water, optimize fracture network development, and aid in the recovery of higher volumes of produced water (Rimassa et al., 2009a; Horn, 2009).

(2) Produced Water

Produced water quality is being scrutinized at increasing levels as development expands to areas without historical resource development and where disposal options are limited. States are imposing more strict limitations on the discharge of produced water, forcing operators to find alternative methods for handling the water (Rigzone, 2010). While historically greater than 95% of the water produced with oil and gas operations have been disposed via injection, development in areas without suitable injection horizons has led to development of alternative methods of disposal, re-use and treatment of produced water in some areas (Veil and Clark, 2010).

Water treatment systems are currently being used and will need to continue to be brought to market to address the issue of produced water quality for disposal and re-use purposes. New technologies for pre-treatment and advances in existing treatment are needed. As the need increases for this technology, existing facilities are expanding capacity and some treatment technologies have become mobile. Even the treatment technologies are adapting to cleaner operations. A new chemical free water treatment system for hydraulic fracturing is undergoing testing and will be added to mobile water treatment systems in the future (Produced Water Solutions, 2011). Not only is the treated water available for future use in hydraulic fracturing operations, it is also of suitable quality to reintroduce into the hydrological cycle, reducing the overall water demands on the system.

BARRIERS AND OPPORTUNITIES

Within hydraulic fracturing technology's advancement and continued use there are barriers to be overcome and opportunities to be explored in the implementation of the technology. The following identified barriers and opportunities have the potential to impact the technology's use today and in the future. Most of the barriers identified deal with the development of unconventional resources and specifically shale gas. This is because at the time of this writing the ongoing research and development work being performed is focused mainly on these types of plays. This does not mean that the solutions to the barriers and the opportunities cannot be translated to hydraulic fracturing in conventional oil and gas resource plays.

L. Barriers

There are a number of areas that have been identified as potential barriers to the continued development and use of hydraulic fracturing technology. Each area has special considerations on how they may impact the technology and at what level that potential impact may be represented.

(1) Regulatory

Many regulatory barriers have been identified that can have an effect on the continued use of hydraulic fracturing technology. Table 3 presents a list of the regulatory barriers of most concern, their potential impact and possible actions to address the impact:

Table 3. Regulatory Barriers for Hydraulic Fracturing.

Barrier	Potential Impact	Suggested Actions
US EPA Hydraulic Fracturing Study (EPA, 2011b)	Federal Regulation of Hydraulic Fracturing as a UIC Activity	Be active participates in the study and review of outcomes derived from study
New State Regulations (Rascalli, 2010)	Additional Reporting and Application Burden on Industry	Work with state regulators to streamline process of application process and reporting data required
Local Community Regulations (Municipalities and Counties)	Limitation on use of Hydraulic Fracturing in a specific area	Requires determination of regulatory authority and jurisdiction on issues being regulated.
Water Availability and Water Boards	Limit access to water sources necessary for development of resource	Determine available water that can be used and identify alternate sources of water if necessary, Acquire proper permits and water rights necessary to develop an area

To address these barriers, industry and technological leaders in the field of hydraulic fracturing need to continue to work hand-in-hand with the regulators to support sound science decisions. Common sense initiatives should be put into place to make sure that the industry is open and willing to work with regulators, supplying them with the information they need to effectively regulate the hydraulic fracturing practice and educate the public.

(2) Economic

Table 4 lists economic barriers that can affect the continued advancement and use of hydraulic fracturing.

Table 4. Economic Barriers for Hydraulic Fracturing.

Barrier	Potential Impact	Suggested Actions
Increased Costs of Job (Materials and man power)	Potential Return on Investment may make development of resource uneconomical	Support the use of domestic resources over imported resources. This includes the support to increased use of natural gas for new domestic energy sources. Increased use of domestic natural gas is believed to help stabilize market forces and therefore stabilize costs for development of the resource.
Cost of Water Management used for High Volume Hydraulic Fracturing	Cost of acquiring, transporting, storing and disposing of water may make development uneconomical	Encouraging the reuse/recycle of produced water and alternate sources of water may lessen the cost of water for development of a resource. Helping to streamline regulatory actions required to acquire water necessary for development and the associated facilities for water management.
Increased Research Costs in Hydraulic Fracturing	Research limited on new resource plays due to high cost of development	Incentives, such as tax credits, are needed to promote the research necessary to continue development of new resource plays. New learning and advancing technology is paramount to developing new resources. Provide assurance to companies that are investing in research that their competitive advantage will be maintained from their investment in research.

When the U.S. develops its native resources, dollars are retained locally, which supports the capital necessary for continue advancement and use of the technologies necessary to exploit the resource. Supporting the use of U.S. natural resources should be an incentive to continue the implementation of the technology and addressing the economic barriers identified.

(3) Technological and Environmental

Table 5 presents technological and environmental barriers that have been identified for the process of hydraulic fracturing as applied in development of oil and gas resources:

Table 5. Technological and Environmental Barriers for Hydraulic Fracturing.

Barrier	Potential Impact	Suggested Actions
Low Percentage of Water Return	Decreases Estimated Ultimate Recovery due to trapping resource in reservoir.	• Encourage the continued research in the development of chemical additives to benefit water recovery or the use of less water in the process of hydraulically fracturing wells. • Encourage research in releasing of the charged system for best water returns. Through the use of measurement of success and monitoring of jobs performed new techniques may be identified that will help in the recovery of water used during a job.
Water Disposal	Water produced after hydraulic fracturing may be difficult to dispose of in certain regions of the country	• Continued research on the development of reuse and recycle processes for use of the produced water. This has an added benefit of also addressing a barrier of water availability by lessening the need for additional source water in completing new wells.
Proppant Placement	Slickwater Fracturing does not have capacity to carry large quantities of proppant into complex fractures	• Encourage more research in the development of new stronger and lightweight proppants that can be more effectively carried by slickwater fracturing jobs. • Research the development of new fracturing fluids that will support the transport of proppant into the complex fracturing created that is necessary to produce resources effectively.
Chemicals	Use of some chemical additives has rasied concerns about potential impacts on the environment	• Encourage the development of "green" chemicals that meet or exceed the job-performance abilities of the chemicals currently being used by the industry.
Intellectual Property and Continued Research on new hydraulic fracturing chemicals or processes	Retention of intellectual property may stall advancement of technology. Release of Intellectual property and removal of competitive edge provides no incentive to continued research.	• When allowing companies the right to hold technology as proprietary, they are provided the incentive to continue investing monies into advanced research to seek a competitive advantage. . • Find and encourage ways for companies to maintain their competitive advantage and maintain proprietary information, but still help in expanding the technology through additional research.

Barrier	Potential Impact	Suggested Actions
Surface Disturbance	Surface impacts in new resource plays may adversely affect local environments and limit development of resource play.	• Encourage the use of new technologies that limit the surface disturbance requirements to performing full field development of resource. Hydraulic fracturing technology is necessary in the use of these new approaches. This includes the use of staged hydraulic fracturing in horizontal wells, centralized fracturing facilities and multi-well pads.
Other Environmental Impacts	Air, Noise, Visual impacts may cause restricted development of resource play	• Encourage the use of technologies that lessen the impacts of the environmental concerns when performing hydraulic fracturing jobs. This may be as simple as effective design and placement of drilling pad locations.

New technological and environmental barriers will be identified as new resource plays are developed. Using existing job performance and monitoring techniques to assess the success of hydraulic fracturing stimulations helps in the advancement of the technology and overcoming the technological and environmental barriers to success. Lessons learned in the development of new resources are likely to be translated to the development of other resources such as more conventional oil and gas as well as previously developed unconventional resources.

M. Opportunities

Table 6 lists several activities that can incentivize the use of the technology and therefore provide for increased opportunity to use hydraulic fracturing in the exploitation of oil and gas resources.

Table 6. Opportunities for Hydraulic Fracturing.

Opportunity	Potential Impact	Suggested Actions
Regulatory Streamlining or Reduction	Increase efficiencies for the development of resource by removing duplicative reporting and permitting efforts	Review current and proposed regulatory initiatives relative to hydraulic fracturing to identify duplicative efforts by multiple agencies. Define regulatory jurisdiction for required components of hydraulic fracturing to assure effective regulation.
Tax Incentives	Encourages the creation of new technology to address known barriers	Provide tax incentives for the use of new technology that addresses specific known issues or barriers in hydraulic fracturing
Technology Development through Research Dollars	Provide atmosphere to encourage development of new technology	Provide research grants to encourage the innovative development of hydraulic fracturing technologies to overcome specific known barriers to use. Research would be open and available for use or refinement by other companies.

NEAR-TERM CHALLENGE

Near-term challenges to hydraulic fracturing technology principally are hurdles being raised by misinformation and misunderstanding of the practice by some public stakeholders and by some regulators. In 2011, the EPA committed to a study on hydraulic fracturing, in the context of the Safe Drinking Water Act (SDWA), and with a timetable for preliminary findings by 2012 (EPA, 2011). It is possible, although by no means certain, that Federal regulation of hydraulic fracturing might follow from the EPA study. In addition, many states have implemented or are in the process of implementing rules and regulations that directly affect not only the reporting of hydraulic fracturing activities and the use of specific materials, but also prescribe how the jobs are to be conducted, what is required for monitoring and reporting, and how produced and/or "flowback" water is managed post-stimulation (Rascalli, 2010). There are also regulatory efforts that do not specifically deal with the process of performing a hydraulic fracturing job, but deal with the acquisition of water permits or rights necessary to accomplish the job. Some attempts to seriously restrict the performance of hydraulic fracturing have been initiated in a few locales.

In a worst case scenario, through the use of regulatory initiatives, the practice of hydraulic fracturing could be halted because of the added burdens placed on its practice. Additional regulatory burdens required for permit application and reporting of chemicals could make development of natural resources through the use of hydraulic fracturing cost prohibitive. A de facto moratorium would be in effect placed on the technology due to these changes in regulation.

An additional near term challenge to the technology is the misperception of the hydraulic fracturing process in the public's eye and how it is portrayed in the media. The potential for misinformation or biased information infusing public opinion on the environmental impacts caused by hydraulic fracturing and the industry as a whole, could spark efforts to limit or halt the use of the technology. Effective and proactive education of the public is seen as one of the best tools to counter act misinformation. Support for non-biased data sources and publication of non-biased information should be encouraged at every level of the hydraulic fracturing community. This information should be compiled and disseminated from objective and non-industry-affiliated entities as much as possible.

LONG-TERM VISION

The evolution of hydraulic fracturing continues to occur as operators and service companies move to "green" chemicals and improved monitoring technologies that facilitate strategy improvements. Future developments are likely to involve the reduction of water usage, larger numbers of environmentally benign chemicals, active treatment systems which reduce the chemical input during a fracture treatment, and movement toward newer technologies to create permeability. In the future the development of artificial proppants which are lighter and stronger than natural materials like sand could result in increased permeability development, higher produced water recover rates (which also reduces the volume of new water to be sourced when recycling is used), and reduction of the health hazards (such as silicosis) associated with the use of silica rich natural materials. The sonic, microwave or foam technologies, when used as carrier fluids instead of water, reduce environmental impacts with less produced water returned to the surface and reduced chemical usage. This can also have a benefit of a reduction in changes to the land surface due to smaller pad size needs.

Monitoring equipment is likely to advance to the degree to which mapping of fracture development will lead to further advances in fracture design to optimize permeability development and maximize contact with the producing formation. Drilling and completion equipment are likely to evolve to facilitate the development of longer laterals, pinnate or other advanced horizontal well drilling techniques to facilitate the production of larger reservoir areas from a single vertical wellbore. Each advancement in development and completion equipment and monitoring equipment can further refine the fracturing process resulting in lower volumes of water and chemical usage, while increase permeability development which should in term lead to increasing gas production volumes.

FINDINGS

- Hydraulic fracturing is an essential technology for producing natural gas and oil from unconventional reservoirs such as coalbed methane (CBM) formations, hydrocarbon-bearing shales and other tight formations with very low natural porosity and permeability. Without the use of hydraulic fracturing, a major proportion of domestic hydrocarbon resources could not be technically or economically produced.

- The foundation of hydraulic fracturing is controlled sub-surface injection of a working fluid at high pressure and with entrained particles of proppant that keep open the artificially stimulated fractures induced by the pressurized fluid. Given the broad variations in reservoir properties, maximum effectiveness of hydraulic fracturing requires tailored modifications for each reservoir-stimulation job, including customized preparations of fluids and proppants.

- Through association with horizontal wells, hydraulic fracturing has helped to drive down the spatial footprints of oil and gas development as an enabling technology for multi-well pads that provide for increased hydrocarbon production and decreased land use. Ongoing refinements to hydraulic fracturing practices will be a key aspect of continuous improvements in resource production using less acreage. Producers also have found practices to mitigate associated impacts such as air emissions and noise associated with drilling activity and also truck traffic.

- Oil and gas producers have invested significant money and effort to refine hydraulic fracturing into a scientific practice that offers commercially beneficial options for a wide variety of hydrocarbon reservoirs in onshore and offshore settings. Customized preparations include variations for different wells and even variations among different completion stages within a single well. Refinements have included optimization of fracture stimulation and retention through use of chemical additives to the fluids which, over time, have been upgraded and reformulated to be more "green" with regard to their safety and environmental neutrality. However, a key to further progress will be collaborations between regulators and producers to accomplish safe and sustainable operations while also assuring the preservation of intellectual property rights for developers of chemical additives and other technologies.

- Since water became the dominant fluid used in hydraulic fracturing, based on field research accomplished over years of work in the Barnett Shale, emerging issues with hydraulic fracturing have featured the volumes and sourcing of the water sent downhole, including chemical additives, as well as the composition and disposition of the water returning uphole.

- Oil and gas producers also have invested significant money and time to reduce overall water requirements and to improve the capability to recycle or re-use water involved in hydraulic fracturing. Advances have included new formulations to allow use of salt water or industrial wastewater as the working fluid and also multiple methods to treat produced water through increasing availability of field-mobilized treatment units.

- Oil and gas producers have further invested money and time to research fracturing techniques that involve little or no water, including using liquefied petroleum gas as the working fluid. Continuing advances will require ongoing commitment to research and development that could be assisted through appropriate regulatory credits or allowances.

- Major barriers to future use of hydraulic fracturing are much more policy-driven than technology-driven. Lack of balanced information and, in some cases misinformation, has created apprehension in some public stakeholders and in some regulators regarding the perceived safety of hydraulic fracturing. Producers must be proactive in addressing public and regulatory concerns to assure that safety and environmental quality is preserved while unnecessary regulatory hurdles are minimized.

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