Hydraulic Fracturing
A Wyoming Energy Forum

SUMMARY REPORT

September 26-27, 2011

The University of Wyoming Conference Center at the Hilton Garden Inn

School of Energy Resources

HAUB SCHOOL & RUCKELSHAUS INSTITUTE
OF ENVIRONMENT AND NATURAL RESOURCES

UNIVERSITY OF WYOMING

Hydraulic Fracturing: A Wyoming Energy Forum

Meeting Summary

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Introduction & Background

The use of hydraulic fracturing to recover oil and gas resources from unconventional geological formations has significantly increased in recent years in Wyoming and elsewhere in the United States. The expanded application of hydraulic fracturing has spurred a significant increase in domestic energy production, and has also generated public concern about the potential environmental impacts of the practice.

Hydraulic Fracturing: A Wyoming Energy Forum convened at the University of Wyoming Conference Center at the Hilton Garden Inn in Laramie, Wyoming on September 26 and 27, 2011. The Forum was sponsored by the University of Wyoming School of Energy Resources and Ruckelshaus Institute of Environment and Natural Resources. The Forum was designed to answer the following key questions: 1) What is hydraulic fracturing? 2) Why and where is it used in Wyoming oil and gas development? and 3) What are the potential environmental impacts associated with its use? The goal was to provide objective information to the public, media, and policymakers about the use of hydraulic fracturing in petroleum and natural gas development in Wyoming.

A Steering Committee composed of representatives from industry, regulatory agencies, and the environmental community guided the development of the forum agenda and selected speakers who represented a diversity of expertise and perspectives on hydraulic fracturing. The Steering Committee designed the forum specifically to examine the technical issues and environmental concerns related to hydraulic fracturing technology and activities directly linked to its deployment. The Forum focused on issues related to hydraulic fracturing, not a broader examination of the role of the oil and gas industry in Wyoming. Desired outcomes of the forum included increased public understanding of the role of hydraulic fracturing in oil and gas development in Wyoming, an index of worker safety and environmental mitigation best practices, and a list of specific research gaps that need to be addressed in the state.

Approximately 400 participants attended the forum, including individuals representing state and federal government, private industry, non-governmental organizations, academic institutions, landowners and the general public. The specific objectives of the Hydraulic Fracturing Forum were to:

1) Share facts about the use of hydraulic fracturing in oil and natural gas development in Wyoming;
2) Explain technical aspects of the fracturing process including the purpose, technology, applications, and results;
3) Review existing state and federal regulations relevant to hydraulic fracturing in Wyoming;
4) Examine potential environmental impacts and concerns associated with hydraulic fracturing and activities directly related to its deployment;

5) Explore worker safety and environmental best management practices that are, or can be, used when performing hydraulic fracturing;
6) Share information about leasing land for oil and gas drilling and hydraulic fracturing operations; and
7) Identify knowledge, data, and technology gaps for future research.

The balance of this report summarizes the proceedings and key outcomes of the Wyoming Hydraulic Fracturing Forum.

Hydraulic Fracturing in Wyoming: Setting the Stage for the Forum

Dr. Mark Northam, Director of the School of Energy Resources, opened the meeting noting that hydraulic fracturing technology is not new, but that its use has expanded rapidly and the technology has evolved in recent years. He said that while the increased application of hydraulic fracturing has brought economic benefits to Wyoming and the nation, it has also generated public concern. Dr. Northam explained that the University is a venue for debating public issues, and that the Forum would provide an opportunity to learn from and have discussion with a diverse group of technical experts on the subject. He said he hoped all participants would be enriched by the event.

Dr. Indy Burke, Director of the Ruckelshaus Institute, also offered opening remarks. Dr. Burke highlighted the role of the University in fostering scholarship and facilitating public education. She cited Wyoming's position as a leading energy-producing state and emphasized the exciting opportunity presented by the Forum to address the high-visibility issue of hydraulic fracturing, with the goal of gaining greater understanding and asking critical questions while striving to set aside values.

The Role of Hydraulic Fracturing in Wyoming Oil & Gas Development

Presentation Summary

Vincent Rigatti, General Manager of the Rocky Mountain Region for QEP Resources, presented an overview of what hydraulic fracturing is, why it is necessary, and how it is used in today's oil and gas plays. The first hydraulic fracturing job (or frac job) was performed in 1948, with more than one million being performed since. The process is used to enhance well performance, with nearly every new oil and gas well in Wyoming (excluding coalbed methane) requiring some degree of hydraulic fracturing to be commercially viable. Much of today's recoverable oil and gas exists in unconventional tight rock formations (shales and tight sands) which, because of their low permeability and porosity, require fracturing to create the pathways to allow hydrocarbons to flow into the wellbore. An intensive sequence of engineering steps, adhering to state oil and gas commission regulations, goes into the wellbore construction and

hydraulic fracturing process to ensure proper well stimulation and the protection of groundwater and freshwater resources. Mr. Rigatti described operations carried out in Wyoming's Pinedale Anticline, one of the richest natural gas fields in Wyoming and the nation, which is an example of how hydraulic fracturing is typically performed in vertical wellbores.

Question and Answer Summary

These key points of clarification and/or further explanation were offered by Mr. Rigatti during the question and answer session:

- The amount of water and sand, and the treating pressure used in a frac job is tailored to each specific well, and is dependent on multiple geological and engineering characteristics, such as the mechanical properties of the formation and down hole pressures.
- The volume or area of rock that is affected or fractured by a frac job is also specific to the geology, and volume of the frac stage at any particular site.
- Considering the depth that most fracture stimulations occur (7,000+ feet), the overlying rock column and the volume of sand and water pumped in each frac stage, it is virtually impossible for a fracture to propagate from the hydrocarbon-bearing formation through the overlying top seal and into the groundwater table at depths around 1,000 feet. However, there have been cases in which aquifers have been contaminated due to leaky well casing with poor cement, or surface spills.
- Perforations are created in the wellbore through a complex, multi-stage process that is carefully calibrated and controlled.
- Information about the composition of fracturing fluids by operator and well site is available at www.fracfocus.org.

The Hydraulic Fracturing Process: Technical Dimensions

Presentation Summary

Kumar Ramurthy, Technology Manager of Rockies Business Development for Halliburton, offered a more technical presentation about the hydraulic process, providing greater detail about well construction techniques, the use of directional drilling (drilling several wells from a single pad on the surface) and the composition of the fluids used in the fracturing process. Surface casing protects groundwater, provides stability for the well bore, and provides well control during drilling. Surface casing depth requirements are set by state or Bureau of Land Management regulations, but are typically 1,000 to 4,000 feet. Production casing provides zonal isolation, well control, and a well path to productive intervals. Cement requirements for production casing are set by state or Bureau of Land Management regulations, as well as operator-instituted requirements. Fracturing fluids are primarily made up of water and sand, with typical blended concentrations of additives amounting to a maximum of three gallons for every 1,000 gallons of water. Modeling procedures are used to design each frac job so that the fluids used are tailored to the geology and resource reservoir at a particular well site.

Monitoring methods used to track and evaluate a fracturing job after it is performed include surface and downhole tilt meters and micro-seismic techniques. Mr. Ramurthy concluded with an overview of a suite of new products that Halliburton is developing to reduce the environmental footprint of hydraulic fracturing, including water treatment and recycling technologies for flowback and produced waters, and alternate fracturing fluid additives derived from ingredients from the food industry.

Question and Answer Summary

These key points of clarification and/or further explanation were offered by Mr. Ramurthy during the question and answer session:

- The price point for natural gas or crude oil at which it is no longer economically feasible to frac a well depends on the cost of well construction and the estimated reserves to be recovered.
- Halliburton posts the additives it uses in frac fluids on the Frac Focus website, and the company no longer uses diesel as an additive.
- The integrity of wellbores is monitored throughout the life of a well including running logs inside the wellbore as well as casing inspection logs.
- Fracturing and other stimulation techniques are used in exploratory wells.
- The amount of frac fluid that flows back (flowback water) depends on the particular well, but typically 20 percent to 40 percent of the fluid flows back; and in some cases, it is as much as 50 percent to 60 percent. Regulations are in place for how to handle flowback water, with a substantial amount of it being treated and disposed of as per regulations, and the industry is moving forward toward re-using the fluids in future frac jobs.
- In deeper wells, high-strength, man-made proppants such as bauxite are used.
- Some of the water used for fracturing is recycled water from previous frac jobs, and some of it comes from industrial water wells.
- Radioactive tracers with a short half-life are sometimes used as a method for monitoring frac jobs, but they are typically added to the fluid by a third party (other than the fracturing service company). The industry is switching toward using green tracers now.
- Water enhancement in shallow coalbed methane wells, such as those in the Powder River Basin, is a different process from hydraulic fracturing. The process involves pumping water (not a fluid mixture) into the well to clean it, enhance production, and stimulate flowback.
- 3D fracture mapping is used to monitor frac jobs while they are in progress, and the data can also be fed into 3D earth models to better map the sub-surface and optimize frac designs in advance.

State Regulatory Landscape for Hydraulic Fracturing

Presentation Summary

Three state agency officials presented information about state laws, regulations, and policies pertinent to the practice of hydraulic fracturing.

Tom Doll, Oil and Gas Supervisor of the Wyoming Oil and Gas Conservation Commission (WOGCC) began the session with an overview of Wyoming's well stimulation rules. Mr. Doll explained that Wyoming has regulated well stimulation since the 1950s and was the first state to implement rules for hydraulic fracturing in 2010. Wyoming's rules cover four key areas: 1) the protection of groundwater and the identification of permitted water supply wells within a quarter-mile of the drilling and spacing unit or WOGGC-approved drilling unit; 2) clarification of requirements for well integrity, casing setting depths, casing design and cementing properties; 3) requirements for disclosure of well stimulation fluid (frac fluid) chemical additives, compounds and concentrations or rates; and 4) requirements for the handling of flowback water.

Mr. Doll reviewed the key stipulations for each area outlined in the state rules and showed examples of the required forms that operators and service companies must supply to the WOGCC. Wyoming is the only state in the nation that requires a well stimulation plan with chemical disclosure be submitted for approval before commencement of the well stimulation program. Trade secret status may be granted for some frac fluid additives, with a total of 146 compounds from 11 suppliers granted trade secret status through August 15, 2011. All trade secret requests and approvals are posted on the WOGCC website (wogcc.state.wy.us). In conclusion, Mr. Doll commented that almost all of the oil and gas wells in Wyoming are treated with hydraulic fracturing to be commercial (except shallow coalbed met natural gas wells in northeast Wyoming), and that the state has not documented any cases of groundwater contamination caused by fracturing.

Todd Parfitt, Deputy Director of the Wyoming Department of Environmental Quality (DEQ), provided an overview of Wyoming air quality and water quality regulations relevant to hydraulic fracturing. Air emissions regulated by DEQ include volatile organic compounds (VOCs), hazardous air pollutants (HAPs) such as benzene, and pollutants designated under the National Ambient Air Quality Standards, such as carbon monoxide, lead, nitrogen oxides, particulate matter, ozone, and sulfur dioxide. Generally, DEQ regulates well development activity before production, including overseeing the implementation of emissions controls, engine replacements, and the permitting of wells. Emissions sources at well sites include production equipment, which is subject to minor source permitting, as well as pump jack engines, tanks, gas collectors and dehydration units. There are three "concentrated areas of development" in the state where requirements for the use of the best available control technologies (BACTs) apply. DEQ has a real-time air quality monitoring network in place, which has shown an overall reduction in VOC emissions and ozone-causing compounds since

2008, likely due to the implementation of voluntary control measures developed collaboratively by DEQ and the industry. National Environmental Policy Act (NEPA) rules apply and an environmental impact statement (EIS) process is executed in cases where a nexus exists with federal lands. NEPA allows for additional controls beyond the normal state regulatory framework.

Mr. Parfitt also covered Wyoming state regulations aimed at protecting groundwater and surface water resources. The surface water program concentrates on preventing impacts from surface activities, such as flowback water spills at drilling sites. Different groundwater classifications are used to determine appropriate uses for groundwater. DEQ administers the Underground Injection Control (UIC) Program on behalf of the U.S. Environmental Protection Agency (EPA) and classifies wells according to what is being put down hole. If a case of contamination does occur, DEQ helps identify the cause of contamination and remediate the impacts. Mr. Parfitt noted two cases in which contamination has occurred were a well blowout in Clark, Wyoming that occurred during drilling and contaminated two shallow alluvial aquifers and one deeper aquifer, and a case in Pinedale where due to a lack of backflow prevention, contaminants were pulled from water supply trucks into an industrial water well when the trucks connected for filling. He said there are lessons to learn from these experiences that can be applied in new areas such as the Niobrara play in southeast Wyoming, including collecting thorough background information on individual well sites before drilling and fracturing occur.

Lisa Lindemann, Groundwater Division Administrator in the Wyoming State Engineer's Office (SEO), reviewed SEO's role in regulating water use in Wyoming. All water in Wyoming is the property of the state under the Wyoming constitution, and an SEO permit is required to appropriate waters of the state. SEO permits define the types of beneficial use allowed under the doctrine of prior appropriation, the area of water use, and the quantity of water allowed for use. Water supply needs for oil and gas development, including fracturing, are short-term or temporary in nature, which translates into three options for industry to obtain necessary supplies: 1) obtain a new water right, which is not difficult unless a basin is fully appropriated and can be processed within one to six months; 2) seek an existing water right and temporarily change the use to oil and gas drilling, which is a common approach and can be done within 30 days; or 3) seek a permanent change of use to an existing water right, which is rarely used because oil and gas needs are temporary and this is an extensive process. Ms. Lindemann explained that groundwater control areas occur where groundwater use is near equal to recharge rates, groundwater levels are declining, conflicts among water users have arisen or are foreseeable, or wasting of water has or could occur. Much of the Niobrara shale play is situated within the same area of the state as the three water control areas designated by the state Board of Control. Because new permits are not available in control areas, temporary water use agreements are the preferred option for obtaining water supply for oil and gas operations in the Niobrara.

Question and Answer Summary

These key points of clarification and/or further explanation during the question and answer session were offered:

- WOGCC monitors compliance primarily by comparing a company's completion report against its pre-approved plan. If an unpermitted action is discovered, WOGCC has the authority to initiate a hearing at which the company may be penalized by a fine or having the bond pulled and being disallowed from working in the state.
- State of Wyoming rules state that operators have 30 days to complete the well, unless they get an extension, and 30 days to submit their completion report after the well is completed or WOGCC can fine them. If a spill or a leak occurs, state and federal agencies are notified of the types of chemicals that are in the drilling fluid as needed (including trade secrets) so that first responders can act accordingly.
- DEQ uses an air monitoring network to protect air quality throughout the state, which has helped DEQ to better understand wintertime ozone levels in Sublette County, and the agency continues to work with industry and the Bureau of Land Management to reduce emissions of ozone precursors.
- The Best Available Control Technologies (BACTs) assigned to a certain air quality permit remain in place over time unless a modification is made to the permit or a new permit is issued, at which time there may be an opportunity to change the required BACTs.
- Unpermitted water wells are difficult for DEQ to protect because the agency lacks information about them so landowners are encouraged to have wells permitted under the grandfather clause that allows them to do so that DEQ is better able to protect them.
- DEQ relies on U.S. Geological Survey data to monitor water wells and other sources of information to monitor the health of groundwater resources. DEQ has a surface water quality program that monitors the health of streams and rivers in the state.

Federal Regulatory Landscape for Hydraulic Fracturing

Presentation Summary

Two federal agency officials presented information about federal laws, regulations, and policies pertinent to the practice of hydraulic fracturing.

Kate Fay, Senior Advisor on Energy and Climate for U.S. Environmental Protection Agency Region 8 first reviewed statistics for oil and gas rig counts in EPA Region 8, illustrating the significant increase in development over the past few years. EPA is interested in these trends because of the potential impact on air and water resources over which EPA has regulatory purview under several key environmental laws, including the Clean Water Act; Safe Drinking Water Act; Clean Air Act; Resource Conservation and Recovery Act; and the Comprehensive Environmental Response, Compensation, and Liability Act. EPA is less directly involved in the regulation of hydraulic fracturing since many states, including Wyoming, have developed their

own rules for the oil and gas industry. However, EPA is considering revisions to regulations for coalbed methane produced waters and new rules for the discharge of flowback water to publicly owned water treatment facilities.

In addition, the Agency is developing a New Source Performance Standard that includes a suite of air quality regulations that would apply to the oil and gas industry, including a subset specifically focused on the completion of hydraulically fractured wells. EPA is also carrying out a Congressionally-mandated study of hydraulic fracturing that will investigate potential impacts on drinking water and identify human health exposure and risk factors, based on a lifecycle approach and research at prospective and retrospective sites around the country. Reports from the study are expected in 2012 and 2014.

Larry Claypool, Deputy State Director of the Division of Mineral and Lands for the Bureau of Land Management (BLM) in Wyoming described BLM's interest and role in overseeing hydraulic fracturing on public lands. BLM has authority over 700 million acres of sub-surface mineral estate, primarily in the West, and most of the oil and gas wells permitted on federal lands will be hydraulically fractured. BLM's Fluid Minerals Program seeks to ensure that oil and gas operations, including fracturing and other well stimulation projects, on federal and Indian lands are prudently conducted through production accountability, protection of the surface and sub-surface environment (particularly water and air resources), and protection of the public health and safety. Fracturing is generally recognized as a standard completion practice that requires no prior approval to be performed on public lands unless additional surface disturbance is required. Related laws, regulations, and policies that help ensure the protection of the surface and sub-surface environment include the Onshore Oil and Gas Order No. 2 for drilling operations, Clean Air Act, and Clean Water Act. Mr. Claypool offered a review of the recommendations from the Secretary of Energy's Advisory Board (SEAB) Shale Gas Production Subcommittee report on hydraulic fracturing, as well as the outcomes of BLM's series of April 2011public forums about the use of fracturing on public lands. Key issues of public concern expressed at the BLM forums were surface impacts, social impacts, well integrity and groundwater impacts, adequacy of public information, and who should regulate the practice.

Question and Answer Summary

Key points of clarification and/or further explanation offered during the question and answer session are:

- The EPA's hydraulic fracturing study is examining questions about the long-term effect of fracturing on the permeability of sub-surface rock and the potential for natural gas to seep into upper geologic layers.
- Air quality issues related to fracturing are still being studied, but much of the emissions appear to come from activities linked to fracturing, such as the compressors and diesel engines used to power the frac job, and truck traffic rather than the fracturing process itself.

- If BLM initiates a rulemaking on hydraulic fracturing on public lands there will be a significant public involvement component to the process.
- In the face of substantial budget cuts, EPA is seeking ways to work smarter and more efficiently with states to address serious issues like air quality concerns related to hydraulic fracturing in a timely manner.

Emerging and Future Technologies for Hydraulic Fracturing

Presentation Summary

Dr. Julio Friedmann, Deputy Program Director for Energy and Environmental Security, and Carbon Management Program Leader in the Office of Strategic Outcomes at Lawrence Livermore National Laboratory, presented information about emerging advanced technologies that hold the potential to transform fossil energy resource development. While the market for domestic shale gas is established, a few key dimensions require advancements for the market to attain maturity. Many stakeholders desire common goals, including increased productivity per well, a reduced well count, and reduced environmental footprint. Dr. Friedmann provided an overview of new simulation and modeling tools, new stimulation and fracturing methods, and new drilling and completion strategies that have potential to help achieve these goals. The suite of new simulation and modeling tools described is intended to make and control fractures in a more fine-grained manner than those currently in use. There are explosives that could serve as an alternative to hydraulic fracturing for inducing fractures down hole, an approach that could potentially increase fracture density, better control geometry, and reduce water use. New drilling and completion designs may also significantly increase sweep, production, and commercially viable shale gas reserves. Dr. Friedmann noted that current federal research and development budgets for unconventional shale gas plays are not commensurate with the technological needs of the industry.

Question and Answer Summary

These key points of clarification and/or further explanation were offered during the question and answer session:

- Reducing well count and improving the productivity of any given stimulation exercise will translate into reduced overall production costs and a reduced environmental footprint, including less water use and less potential for methane leakage into groundwater sources.
- Currently no good data are available regarding how much gas is left in a well after production ceases.
- A wide range of high-energy explosives exist that may be suitable for stimulating sub-surface fractures for shale gas production, but no field tests have yet been performed.
- Dedicated, long-term field testing is necessary to validate new simulation models.

- The development, validation, and commercial implementation of new well stimulation technologies will require multi-disciplinary approaches and effective public engagement and communication.

Potential Environmental Impacts of Hydraulic Fracturing Technology and Directly Linked Activities: Water Quality and Water Supply Concerns

Presentation Summary

Dr. Suzanne Paschke, Associate Director for Hydrologic Studies at the U.S. Geological Survey (USGS) Colorado Water Science Center, explained that water concerns related to fracturing center on the amount of water used in the process and the potential for the chemical additives in frac fluid to contaminate underground sources of drinking water as well as surface waters. Groundwater is the primary source of drinking water for 80 percent of Wyoming's residents. The large volumes of water used for hydraulic fracturing could potentially lower water tables, dewater drinking water aquifers, and result in decreased stream flows. Dr. Paschke commented that recycling and reusing flowback and produced water helps reduce use of groundwater resources for fracturing.

In terms of water quality concerns, increased groundwater pumping can change subsurface pressure gradients and groundwater flow directions, which can change subsurface movement of natural gas and frac fluids. Increased downward pressure gradients also increase the vulnerability of aquifers to effects from activities on the land surface. Improper handling of fluids (chemical mixing, flowback or produced waters) at the land surface can contaminate shallow aquifers. Flowback water consists of frac fluid that returns to the surface. Produced water is naturally occurring sub-surface water that flows to the surface as a result of well stimulation. For example, flowback water stored in unlined pits can leak to underground sources of drinking water. Well failure or poor construction, errant fractures or faults, and improperly sealed abandoned wells can lead to leakage of frac fluids to adjoining drinking water aquifers.

Dr. Paschke outlined opportunities for future research on water concerns related to fracturing. Opportunities included basin-wide approaches to assess the overall status of drinking water resources; site-specific monitoring in active oil and gas development areas using fracturing; establishing pre-development baseline groundwater levels and groundwater and surface water quality; and periodic and possibly long-term monitoring of drinking water wells and streams near development areas. She concluded with a description of a water quality monitoring study USGS conducted in the Piceance Basin of Colorado and highlighted the Powell Center Initiative to synthesize USGS datasets to identify potential effects of hydraulic fracturing on water resources.

Question and Answer Summary

Key points of clarification and/or further explanation offered during the question and answer session were:

- Federal agencies such as USGS or EPA may be available to conduct baseline water quality studies in cooperation with state agencies.
- It is up to state regulatory agencies to determine next steps regarding further investigation if/when a substantial change in water quality is detected relative to an established baseline.
- There are many differences in the orders of magnitude in how fast groundwater moves through unconsolidated sand or gravel (approximately 100 feet per day) as compared to consolidated sandstone or tight rock (approximately 0.1 to 0.5 feet per day).

Presentation Summary

Dr. Ann Maest, Managing Scientist, Stratus Consulting, Inc., focused on the potential environmental effects of hydraulic fracturing activities on surface waters, particularly the management of flowback and produced waters. Publicly available data specifically about the management of flowback water are sparse, partly because oil and gas operators are not required to separately report fracturing fluid flowback and produced water volumes. Dr. Maest's material was based on a 2010 National Academy of Sciences study titled *Management and Effects of Coalbed Methane Produced Water in the Western United States*, for which the Powder River Basin in northeastern Wyoming was one of the regions examined,[1] and other studies of the environmental effects of produced water in Wyoming. While hydraulic fracturing is not used in the shallow coalbed methane (CBM) plays of the Powder River Basin (PRB), it is possible that fracturing will be used more in the region as deeper gas deposits are accessed. Currently, water enhancement is used to stimulate wells in the PRB, which is similar to fracturing except without the use of chemical additives. Though not directly related to the practice of fracturing, concerns related to the management of produced waters from oil and gas development in the PRB region are instructive.

Dr. Maest described the typical composition of oil and gas and coalbed methane produced waters in wells throughout Wyoming, highlighting that total dissolved solids are a concern, as the produced waters from a substantial number of wells exceed the Wyoming water quality standards for agriculture and livestock watering. She reviewed a number of potential pathways, such as surface impoundments, through which untreated flowback or produced waters could pollute water sources and potentially harm wildlife. Some of the observed environmental effects related to produced water discharge in Wyoming include increasing arsenic and

[1] *Management and Effects of Coalbed Methane Produced Water in the Western United States* can be found at: http://dels.nas.edu/Report/Management-Effects-Coalbed-Methane/12915.

selenium concentrations in ephemeral drainages and shallow groundwater (from dissolving of pre-existing salts), increased ammonia concentrations in the Powder River, uptake of benzo(a)pyrene by birds in created wetlands, and decreased diversity in native plants in areas with land-applied CBM produced waters. Most of the produced water in Wyoming is recycled and reused for drilling, enhanced oil recovery, or fracturing. There is relatively low potential for surface impacts from the subsurface piping of flowback and produced water for recycling, but there are no regulations related to recycling, and the potential for spills or leaks does exist.

In terms of future research, Dr. Maest recommended more studies on the potential environmental effects of flowback and produced waters, including field studies to evaluate the effects of flowback and produced water on native plant species and aquatic biota; track the constituents of flowback and produced waters through all components of the ecosystem; and track how fracturing affects the subsurface movement of natural contaminants through the creation of new pathways. In addition, she suggested a need for separate accounting of flowback and produced water volumes and more thorough analyses of flowback and produced water samples for trace metals and trace organics, beyond dissolved solids and sodium.

Question and Answer Summary

These key points of clarification and/or further explanation were offered during the question and answer session:

- Surface impoundments of flowback and produced waters pose some potential risk to game birds.
- The University of Wyoming Department of Veterinary Sciences participated in a study that examined the potential health effects of inorganic compounds in livestock water, which covered CBM produced waters.
- The state would be able to fill some of the data gaps regarding flowback water composition if operators were required to report that information separately. Currently, necessary treatment for combined flowback/produced waters is dependent upon the composition and can range from evaporative impoundments to surface spreading to disposal at a hazardous waste facility.
- Possible methods for distinguishing between flowback and produced water include measuring based on a time interval because produced water does not flow up the well until after 10 days, and/or to conduct chemical analysis to distinguish by level of salinity (produced water typically has higher levels).

Potential Environmental Impacts of Hydraulic Fracturing Technology and Directly Linked Activities: Air Quality Concerns

Presentation Summary

Dr. Robert Field, Associate Research Scientist with the University of Wyoming Department of Atmospheric Science, discussed potential impacts on air quality associated with hydraulic

fracturing technology and directly linked activities. Natural gas is made up of methane and volatile organic compounds (VOCs), with the relative amount of each constituent being dependent on the source formation. Air quality concerns related to natural gas development and hydraulic fracturing center on the fact that methane is a greenhouse gas; VOCs such as benzene, toluene, ethylbenzene, xylene (BTEX compounds) are known to be toxic/hazardous pollutants; and VOCs and nitrogen oxide are precursors to ozone formation. Elevated wintertime ozone levels have emerged as a concern in some areas of Wyoming in recent years, particularly in Sublette County. Dr. Field is focused on air emissions associated with the production phase of oil and gas development, which includes well completion and hydraulic fracturing. The production phase accounts for more than over 60 percent of emissions from oil and gas development, with well production venting and flaring accounting for 50percent of the emissions in that phase.

Dr. Field explained the key steps in how a producing well works to point out where certain types of air emissions can occur. In the context of well completions and hydraulic fracturing specifically, emissions sources include high-torque diesel engines to run the necessary machinery on-site; venting, flaring and fugitive emissions that escape; and emissions released during the process of managing flowback water. Control technologies, known as "green completions," can be used to reduce the level of emissions from the well completion process. In Wyoming, green completion permits have been required in the Pinedale Anticline and Jonah Field area since 2004 and in the concentrated development area of southwest Wyoming since 2007. These permits require companies to use best management practices (BMPs) to reduce well completion emissions by selling flowback gas rather than flaring or venting the gas. They also require companies to monitor and report on their use of BMPs, and document circumstances when green completions are not possible. The EPA's proposed New Source Performance Standard would also require green completions and apply to all wells that are fractured or re-fractured.

Dr. Field concluded with an overview of relevant air quality research ongoing at the University of Wyoming, highlighting the need to collect more data about well completion emissions. Other areas for future research include tools for pre-development air quality monitoring such as mobile methane monitors that regulators and industry could use, as well as matching monitoring measurements with operators' emission inventories.

Question and Answer Summary

These key points of clarification and/or further explanation offered during the question and answer session were:

- In the absence of green completions, most constituents of air emissions from well completions are likely to be flared and not to be deposited on the landscape, but it depends on the particular field.

- Operators and regulators have implemented concrete improvements that have led to reductions in air emissions associated with well completions, but generally decreased production resulting from an event such as the national economic downturn would also influence emission levels.
- Dr. Field was not aware of any studies regarding the potential effects on surface water quality of snowmelt containing deposited pollutants from oil and gas development air emissions.

Pavillion, Wyoming: What are the History and Status of Environmental Concerns? What Have we Learned from the Experience?

Presentation Summary

The Hydraulic Fracturing Forum Steering Committee included a session about Pavillion, Wyoming on the Forum agenda because of the widespread public interest in the case among Wyoming residents. To date, no conclusions have been reached about the source of the constituents of concern found in private water wells. Three agency personnel familiar with the ongoing investigation into the cause of contamination in Pavillion presented information and participated in a panel discussion about the case.

John Wagner, Administrator, Wyoming Department of Environmental Quality, Water Quality Division, provided an overview of relevant DEQ regulations and explained the nature DEQ's involvement in the Pavillion case as a function of those regulations. The quality of water at the tap in public systems is protected and regulated by federal law in Wyoming, while the quality of water at the tap in private systems is not regulated by federal or state law. The town of Pavillion's water supply is public (15 service connections or serves more than 25 persons), but water wells at single-family residences outside town are private. In terms of regulations related to drilling and fracturing, Wyoming DEQ has primacy for most UIC program permitting, construction grants and operator certification, but WOGCC has UIC primacy for disposal of oil field brines to non-underground sources of drinking water and for enhanced oil recovery injections. This combination of regulations means that state agencies may not regulate the quality of water at the tap in private systems, but do have responsibility for protecting source water such as aquifers. DEQ classifies aquifers into six use classes based on the natural water quality (domestic, irrigation, livestock water, industrial, economic, and unusable). EPA classifies aquifers only as underground sources of drinking water (USDWs) or not USDWs, primarily based on the level of total dissolved solids. DEQ classifies any aquifers being used for domestic purposes as Class 1(domestic use).

Mr. Wagner summarized the status of water quality in Pavillion relative to these regulations. To a degree, testing has shown that the natural groundwater being used for domestic purposes in Pavillion has been degraded below DEQ's Class 1 criteria. The cause of the identified degradation is not yet known, but DEQ suspects the presence of some of the detected organic compounds is related to historic drilling, well completion, and fluid management practices. In

terms of remediation, he stated that the most practical approach is probably to eliminate the source and monitor the area to track natural cleanup processes instead of attempting to proactively clean up the aquifer to meet Class 1 criteria. Alternatives to cleaning up groundwater would be to construct a centralized water system for the affected homes or implement "point of use" treatment systems.

Ayn Schmit, Unit Chief, Watershed & Aquifer Protection Unit, U.S. Environmental Protection Agency Region 8, presented background on EPA Region 8's investigation of groundwater and water well problems in Pavillion, and reviewed the latest information from EPA's sampling and monitoring process aimed a identifying the source of constituents of concern. EPA is responsible for protecting USDWs and was approached by Pavillion residents in 2008 regarding water quality problems. In consultation with WY DEQ and area Tribes, EPA conducted sampling of domestic wells in March 2009 and January 2010, and also installed monitoring wells in 2010. The work was conducted as a Superfund site investigation of groundwater, not monitoring of a public water supply system. The first two phases of well sampling focused on constituents in drinking water wells and associated health risk, along with domestic wells as indicators of the overall condition of the aquifer. Ms. Schmit reviewed the results of the first two phases of sampling, which detected constituents of concerns in several wells including thermogenic methane (thermal gas generated in deep gas reservoirs), diesel- and gasoline-range organics, and other organic compounds including 2-BE phosphate, phenols, and adamantantes. Based on these results, the Agency for Toxic Substances and Disease Registry (ATSDR) recommended that affected residents use alternate water for drinking and cooking. Phases 3 and 4 were ongoing at the time of Forum, and included data collection from two aquifer monitoring wells and samples from 11 domestic wells.[2]

Ms. Schmit noted that although the specific cause(s) of contamination in Pavillion are not yet known, it is important to recognize that drinking water and oil and gas resources are often co-located in the West, which may present higher risks of impacts to USDWs. Key lessons from the Pavillion case are that baseline water quality monitoring is critical for the scientific assessment of impacts, and that state and federal agencies that share responsibilities for preventing and/or mitigating impacts to drinking water resources need to collaborate and share information.

Tom Doll, Oil and Gas Supervisor, Wyoming Oil & Gas Conservation Commission, described the latest information from the two working groups (as of August 31, 2011) convened to provide input into the Pavillion groundwater investigation. The groups were charged with examining pits and gas well integrity in the area of concern, respectively. WOGCC and DEQ led the working groups, which also included participants from SEO, EPA, BLM, Encana, and local

[2] Background and current information about the U.S. EPA's groundwater investigation in Pavillion, including materials from the November 9, 2011public meeting at which Phase 3 and 4 results were presented, can be found at: www.epa.gov/region8/superfund/wy/pavillion.

landowners. On behalf of the Pit Working Group, Encana collected soil samples at 11 of the potential 32 sites of concern to landowners because of potential shallow groundwater contamination from oil field development. Analysis of the samples is the next step toward identifying potential remediation sites and reaching closure on the pit investigation. On behalf of the Well Integrity Working Group, Encana had run bradenhead pressure tests on 34 of the 169 wells in the Pavillion area. Only four of those wells were found to have pressure above 0 psi, with two well casing-annulus pressure exceeding 100 psi. These wells were flagged for remediation, and further discussion was scheduled to reach closure on investigation of well integrity. Mr. Doll explained that a Wyoming State Geological Survey analysis showed that natural gas from Cody shale and possibly Meeteetse shale migrates directly into the Wind River formation where Pavillion is located, and that the Waltman shale that normally acts as a sealing formation does not exist in the Pavillion area. He also noted that the Water Development Commission presented its study of alternative water supply at a public meeting in Pavillion on September 7, 2011.

Panel Discussion Summary

Following their presentations, the panelists engaged in a brief discussion about lessons learned from the Pavillion case to date, before fielding questions and comments from participants. EPA Region 8 was able to obtain funds to conduct the Pavillion groundwater investigation and serve as an independent party, which was fortunate because some local people did not trust a well operator to collect and analyze samples. The investigation is focused on determining whether the aquifer is contaminated and does not involve addressing specific, private water wells. Groundwater investigations are complex undertakings that require inter-agency collaboration and resident/landowner participation, as well as industry involvement in some cases. There remains room for state and federal agencies to improve their ability to carry on these types of investigations in a well-coordinated and cost-effective manner. A key issue highlighted by Pavillion is the need to conduct pre-development baseline water quality testing before drilling and fracturing occur. The case also points to how important it is for landowners and residents with unpermitted wells to report water quality problems to regulatory agencies so they can determine what is happening in the aquifer.

Question and Answer Summary

Panelists offered the following points of clarification and/or further explanation during the question and answer session with participants:

- Landowners in Pavillion have contributed valuable information based on personal observation to the investigation and working group process. It is important that affected stakeholders have a voice in these types of processes.
- In the context of federal lands, a NEPA process is required before drilling and fracturing occur, which affords a designated opportunity for the collection of baseline water quality data through the environmental impact statement process. Currently, there is no comparable measure at the state level.

- It is not yet known what the source of the 2BE phosphate in Pavillion water wells may have been, but it is a common chemical used as a flame retardant in flowback water storage pits.
- With 2000 UIC permits in Wyoming, state regulatory agencies do not have sufficient funding to conduct as much permit compliance monitoring as they would like. WOGCC monitors wells quarterly and inspectors check on wells over the course of the wells' lifespan. The agency also has a program to conduct mechanical integrity tests and only eight wells out of 1,400 tested have failed, so the overall risk is low. Generally, WOGCC strives to establish cost-effective programs that serve as a deterrent, and focus enforcement attention on bad actors as a risk management strategy.
- All WOGCC funding comes from a conservation tax levied on the oil and gas industry, and the Oil and Gas Supervisor must adhere to the guidance provided by the Governor in terms of the agency's budget.
- EPA is not currently in a position to fully fund state UIC programs.

Hydraulic Fracturing Best Management Practices: Ensuring Worker Safety

Presentation Summary

Jack Bedessem, CEO and President of Trihydro Corporation and Vice President of the Board of the Wyoming Oil and Gas Industry Safety Alliance (WOGISA), and J.D. Danni, Deputy Administrator of the Wyoming Occupational Safety and Health Administration (OSHA), delivered a joint presentation on worker safety best practices for the oil and gas industry, including hydraulic fracturing. Mr. Bedessem provided an overview of pertinent industry safety statistics and then focused on the work of WOGISA. WOGISA strives to attain incident-free oil and gas operations in Wyoming by promoting industry safety and health improvements, fostering work environments that rely upon open communication and trust, and enhancing Wyoming safety culture. Among its many activities, WOGISA develops and delivers safety-oriented training programs, works with legislators on pertinent legislation, and coordinates efforts with regional and national safety organizations.

Mr. Danni explained the role of Wyoming OSHA in overseeing worker safety in the state, which includes ensuring compliance with state rules, offering consultations to employers, and delivering free training programs. Several rules apply specifically to the processes involved in performing hydraulic fracturing, including measures for fire/ explosion prevention, personnel positioning and spacing requirements, and testing of pressurized devices. Wyoming OSHA is also proposing a set of new worker safety rules for drilling operations.

Mr. Bedessem commented that worker safety best practices center on creating and sustaining a culture of safety within companies and throughout the industry in Wyoming. A culture of safety depends on an effective combination of state and federal regulations, company programs and requirements, and company and employee commitment. Regulations provide a general framework for safety. Companies need to provide the necessary tools and equipment; up-to-

date training, programs, and policies; support to make well-informed decisions; and time to perform work safely. Employees must recognize that safety is ultimately a personal responsibility and strive to set a good example for others.

Question and Answer Summary

Key points of clarification and/or further explanation offered during the question and answer session were:

- The National Institute for Occupational Safety and Health (NISOH) is conducting a study to assess chemical exposure risks to oil and gas industry workers.[3]
- WOGISA does not currently cover issues related to alcohol and substance abuse in its training programs but may incorporate the topic in the future.
- OSHA trains oil and gas industry employees in how to handle exposure to harmful air chemicals and offers consultation assistance to employers to help address related questions.
- The state's worker safety rules establish a minimal regulatory framework and OSHA encourages employers to implement safety practices above and beyond state rules. OSHA strives to offer employee training that will equip workers to recognize safety issues as they encounter them and be safe in unforeseen circumstances.
- Generally, oil and gas companies in the state comply with state rules and have developed good cultures of safety, but some are non-compliant.
- OSHA uses worker's compensation data to evaluate overall progress in improving worker safety and to determine where to focus on the development of new rules and legislation.

Hydraulic Fracturing Best Management Practices: Mitigating Environmental Concerns

Presentation Summary

Briana Mordick, Oil and Gas Science Fellow, Natural Resources Defense Council, discussed environmental mitigation best practices for hydraulic fracturing, including pre-planning and site characterization, well construction, and pre-frac, concurrent, and post-frac monitoring practices. Before fracturing, baseline testing of groundwater and surface water resources and conducting a geochemical analysis of the hydrocarbons and connate water present in source rock as well as the producing and confining formations are important steps. The geologic suitability of the formation should also be assessed including structure and stratigraphy, local

[3] More information about this NIOSH study is available at: http://www.cdc.gov/niosh/docs/2010-130/pdfs/2010-130.pdf

and regional hydrology, the areal extent and permeability of confining zones, and the anticipated impacts of fracturing (on conductivity, porosity and permeability, hydrology, rock mechanics, etc). Detailed models based on relevant geologic and engineering factors should be constructed to help determine the "zone of contact" of the induced fractures (i.e., the physical and chemical extent of fractures and displaced fluids), and consider cumulative impacts. Existing and abandoned wells within the zone of contact should be evaluated and repaired as necessary to prevent them from becoming pathways for injected or displaced fluids to migrate into drinking water.

Operators and service companies should also have plans for managing cumulative water use and wastewater handling that outline key aspects such as the source, timing, and necessary volume; methods for on-site storage, maximizing recycling and non-potable water use, and mitigating environmental impacts; chemical additives to be used; produced water composition; and assessment of disposal options. Wells that will be fractured must be constructed, starting with careful selection of drilling fluid and proper hole cleaning and conditioning to ensure a strong bonding of cement and casing. Wells must isolate drinking water from brines, hydrocarbons and other contaminants and should be tested using casing pressure tests, cement compressive strength tests, casing show tests, and cement evaluation logs. Operators should develop comprehensive plans for groundwater monitoring before and after hydraulic fracturing takes place, including installation of appropriately spaced, dedicated groundwater monitoring wells.

During hydraulic fracturing, actual fracture growth and placement should be measured using tiltmeters, microseismic techniques, and possibly tracers in fracturing fluid. Ms. Mordick emphasized that none of these concepts or practices is novel and should be employed by prudent operators, but the extent to which they are used is unclear. Greater transparency about when and where the methods are being used could address some concerns among the public.

David Burnett, Director of Technology at Global Petroleum Research Institute, Department of Petroleum Engineering, Texas A&M University, described a number of additional environmental mitigation best practices under development by the Environmentally Friendly Drilling Systems Program (EFDS; www.efdsystems.org). The EFDS Program is supported by a broad array of environmental organizations, academic institutions, state and federal agencies, and oil and gas companies. Innovations in well site access and drilling methods, such as horizontal drilling combined with fracturing, have helped minimize surface land impacts by maximizing the amount of reservoir that can be accessed from a single well pad. Other products and methods are under development, such as small footprint drilling rigs and rollout roads made of heavy-weight composite fencing that hold potential to further mitigate surface disturbance from drilling rigs. Work is ongoing to identify alternatives to reduce the footprint of hydraulic fracturing through centralized frac facilities that involve offsite operations and innovative fracturing technologies, such as a novel process using minimal pumping equipment, low volumes of frac fluid, and green additives. Centralized facilities would also require less energy to operate and reduce overall air emissions. Additional environmental mitigation tools

under development include acoustic fences to mitigate noise impacts, handheld air quality monitoring devices, membrane treatment methods for recycling flowback and produced water, and mobile field site water treatment systems. Techniques for on-site brine (produced water) treatment and analysis are also under development. Dr. Burnett concluded by noting several agencies and organizations in addition to the EFDS Program that are working to develop and rollout environmentally friendly drilling practices.

Question and Answer Summary

Key points of clarification and/or further explanation offered during the question and answer session were:

- Both radioactive and chemical tracers can be used for tracking the placement of frac fluids in the sub-surface. Typically, the proppant (sand) is tagged with the tracer and then injected, and a tool is put down the wellbore to determine in which perforation the tracer was placed.
- Research institutions are working on the development of field-portable dissolved methane detectors/sensors.
- Casing and cementing in the intermediate zone between the base of the surface casing and top of production casing of the wellbore are important because stray gas migration may pose greater risk to groundwater than frac fluids. Currently, only the State of New York requires cementing in that zone.
- Fast-tracked regulatory processes or tax incentives are two possible avenues to facilitate the implementation of new environmentally friendly drilling and fracturing technologies.
- Biocides are added to frac fluid stream in the same manner as sand is and must be handled safely.
- Incorporation of a health impacts assessment into the pre-planning stage of drilling and fracturing, conducted in collaboration with local organizations and institutions, may be a useful step toward addressing public health concerns.
- Pre-planning and site characterization should include identification of abandoned wells that could be within range of a planned frac job to prevent fluid migration into potentially degraded wells that could serve as conduits to a groundwater aquifer.
- Flowback and produced waters have high salinity concentrations, but not typically so high that they cannot be treated sufficiently to be re-used for fracturing.

Landowner Information: Leasing Land for Oil and Gas Drilling and Hydraulic Fracturing Operations

Presentation Summary

The Hydraulic Fracturing Forum Steering Committee included a session focused on leasing land for oil and gas drilling and hydraulic fracturing operations because of the increasing rate of oil and gas development in the state and the associated demand for information among

Wyoming landowners and residents about what to expect and how to negotiate the leasing process.

Randy Reed, Partner, Dray, Dyekman, Reed, Healey P.C., provided an overview of important legal concepts in oil and gas leasing including split estate law, surface use agreements, and pooling. A split estate occurs when the owner of the surface is different from the owner of the minerals beneath the surface. There are several scenarios under which a split estate can occur. Under Wyoming split estate law, the mineral estate is deemed to be the dominant estate and the surface owner cannot prevent the development of the minerals beneath his property. The law allows an oil and gas operator to enter the land in order to conduct "reasonable and necessary" activities to conduct oil and gas operations. Entry upon the land for oil and gas operations is conditioned upon providing notice, attempting good faith negotiations; and securing a written waiver, surface use agreement or consent from the surface owner or posting a bond with the Commission to secure payment of damages. The oil and gas operator is strictly liable and must compensate the surface owner for damages such as (but not limited to) loss of production and income, loss of land value, and loss of value of improvements caused by oil and gas operations, and disruption.

A surface use agreement (SUA) is a contract between an owner of the surface estate and an oil and gas operator seeking to develop the minerals beneath the surface. SUAs are useful in both split estate and non-severed mineral situations. If a SUA is not reached, the company can "bond on." Generally, landowners should strive to negotiate a surface use agreement at the time of leasing. If minerals are leased without a SUA, it is a split estate situation. There are a number of typical provisions that landowners should seek to include in a SUA. Many relate to how drilling operations will be carried out on the land as well as compensation and reclamation provisions. Recommended provisions related specifically to hydraulic fracturing include collection of baseline water quality data at the cost of the company; ongoing monitoring of water quality and quantity; specific stipulations for how flowback/produced water will be handled and for how the well will be constructed (i.e. surface casing to a depth sufficient to protect artesian water sources). Landowners should also consider provisions for equipment storage, dust suppression on nearby private and public roads, and a full indemnity covering all damages caused by operations. SUA enforcement mechanisms should also be made clear in the agreement.

Voluntary pooling is the process by which separately owned tracts or interests (both royalty and working interest) within a drilling unit are merged to share in the development and production from any well completed on the drilling unit. Pooling is intended to prevent waste and maximize the recovery of oil and gas, protect correlative rights, control the density of wells, and achieve equity among the various interest owners in a common reservoir by permitting each to recover their fair share of the oil/gas or the associated proceeds. In the absence of voluntary pooling, the WOGCC may force pooling all interests in the unit for development of the pool (a.k.a. compulsory pooling). This method may be used to compel uncooperative owners to participate in drilling or give up their rights in return for fair compensation. Forced

pooling can only be ordered after notice and a hearing, and upon terms that are "just and reasonable."

William Obourn, Senior Landman, Alfson Energy Land Services, offered a landman's perspective on the process of oil and gas leasing. Landmen conduct preliminary research on prospective lease opportunities, investigating who possess surface, mineral, and leasehold rights for a parcel of interest. Surface inspections of prospective sites provide a sense of the likely terms of the lease and SUA provisions based on the quality and level of maintenance of various features of the property. Areas of negotiation include bonus, term, and loyalty in the oil and gas lease; SUAs; and pooling. Mr. Obourn stated that forced pooling should not be used as a threat, but should be discussed if the landowner/mineral owner asks about it. However, most oil and gas leases can be negotiated without discussing forced pooling. Landmen should treat landowners fairly, honestly, respectfully, and follow through on commitments. The American Association of Petroleum Landmen is a forum where landowners can voice concern about a landman, which can trigger an investigation and penalties. Landowners should be aware of the differences between an operator and speculator, as well as a company landman and broker. Educating oneself, making observations about the landman, and seeking legal advice are all important steps landowners can take to ensure a fair lease negotiation.

Pat O'Toole, Owner/Operator, Ladder Ranch; President, Family Farm Alliance, provided a rancher's perspective on the increasing rate of oil and gas development in Wyoming and the impacts on landowners and natural resources that farmers and ranchers depend upon. From his perspective, fracturing has been a "game changer" in the oil and gas industry like the green revolution was in agriculture. Development has been so rapid and heavy in some areas of Wyoming that farmers and ranchers have abandoned their land. Mr. O'Toole emphasized the need to balance competing needs for water resources among agricultural producers, energy developers, municipalities, and the environment. He said that extensive fracturing should not be permitted to consume water resources at the expense of food production or environmental health.

Deb Thomas, Organizer, Pavillion Area Concerned Citizens; Powder River Basin Resource Council; Clark Resource Council, provided a citizen's and landowner's perspective about concerns regarding the impacts of hydraulic fracturing on land, water resources, and public health. The volume and variety of chemicals used in frac fluid and their potential impacts on drinking water aquifers, air emissions, and reduced property values are three key areas of concern among residents and landowners. For example, property values for some landowners in the Pavillion, Wyoming area have been diminished by up to 50 percent. Landowners are concerned about the potential health impacts of accidents such as the Clark, Wyoming case in which a well blew out during drilling, and chemicals were released into the air and are believed to have caused human health impacts to area residents. Ms. Thomas recommended a number of provisions for landowners to consider when negotiating a lease for drilling and hydraulic fracturing operations, including baseline monitoring of water quality and ozone levels; comprehensive and continuous water, air, and soil quality monitoring; human health

assessments; comprehensive emergency and first response plans; independent analysis of property values before, during and after development; and specific bonding to cover reclamation. She also emphasized that operators should be required to fully disclose to landowners and the public all chemical additives used throughout the lifecycle of exploration and development, including but not limited to those in drilling, hydraulic fracturing, and in well scrubbing fluids.

Question and Answer Summary

Panelists offered the following points of clarification and/or further explanation during the question and answer session with participants:

- Good faith leasing negotiations are often facilitated by face-to-face meetings, and attorneys can also help ensure negotiations occur in good faith.

Mike Sullivan, panel moderator, former Governor of Wyoming, and Partner at Rothberger, Johnson and Lyons, offered closing remarks to conclude the panel session. He said a culture of cooperation, communication, collaboration, and consideration is necessary for different stakeholders and interests in the hydraulic fracturing debate to work together to resolve outstanding questions and address concerns. In addition, worker safety rules and regulations ought to go beyond the bare minimum because minimal rules do not protect those working in situations where the desired culture of safety does not exist.

Knowledge, Data and Technology Gaps for Future Research

Presentation Summary

To open the final session of the Forum, Dr. Northam and Dr. Burke presented a summary of research questions that emerged from presentations and discussion throughout the meeting. The following questions relate specifically to the technology and processes involved in hydraulic fracturing:

- How might industry reduce the net water use of hydraulic fracturing?
- How might treatment of flowback and produced water be made more effective?
- How might regulatory agencies facilitate the rapid and broad implementation of green fracturing and completion technologies?
- What types of tracers are available for monitoring sub-surface migration of fracturing fluid?
- How can the occurrence and orientation of natural fractures and fissures be better predicted, and how can that knowledge be applied to improve fracture creation?
- How might the testing and validation of new technologies be advanced to optimize well stimulation and mitigate environmental impacts so that they may be commercially deployed? What are the technical hurdles? Institutional hurdles? Regulatory hurdles?

- How can we use technology to improve the efficiency of recovery of oil and gas after hydraulic fracturing, and increase ultimate recovery early in field development?

The following research questions relate to potential water, air and public health impacts from hydraulic fracturing:

- How do hydraulic fracturing and directly linked activities influence groundwater, air quality, and other ecosystem resources?
- How should monitoring before (i.e., baseline), during, and following development activities be accomplished to increase knowledge about impacts, and guide activities during the development process? Goals should include basin-wide, stratified random sampling and consistent long-term measurements for both air and water quality.
- What types of incentives might be developed to foster partnerships among regulatory agencies, industry, and landowners that would facilitate baseline and ongoing monitoring and help inform permitting agencies?
- Given the well-known adverse effects of exposure to hazardous substances, what technologies can be developed or employed to significantly reduce air emissions from fracturing operations?

The following research questions relate to worker safety practices:

- Are there best practices being implemented by certain operators and/or service companies that ought to be implemented statewide? If so, how can such practices be brought to light and shared within the industry?

Additional Research Questions from Plenary Discussion and Written Input

Following Dr. Northam and Dr. Burke's review of research questions, forum participants engaged in small group discussions. Below, key questions, outstanding concerns, and suggestions raised by participants during the plenary discussion and in writing thereafter are presented.

<u>Hydraulic Fracturing Technology</u>

- Further research and development of modeling and mapping technologies for characterizing site geology and tracking induced fractures in the sub-surface.
- Is there a correlation between the acid used in cementing and the strength of the cement?
- Longitudinal research on integrity of wells post-production. What are the potential impacts of widespread development and fracturing in 30 to 50 years?
- Which chemical additives in frac fluid pose the greatest ecosystem and human health risks?
- What is the cost comparison between conventional fracturing fluid and new green fracturing fluids?

- Further research and development of alternative well stimulation technologies such as explosive fracturing, that may reduce overall environmental impacts.
- Economic studies to determine effective incentives to promote implementation of emerging environmental mitigation technologies and green completions.

Regulation

- Establish requirements and protocols for hydraulic fracturing that incorporates baseline water and air sampling, emergency/contingency plans, and greater overall specificity than the existing WOGCC rules (i.e. beyond frac fluid disclosure).
- Establish baseline air, water and soil quality monitoring protocols that apply across the state.
- Provision of site-specific geologic information that illustrates sub-surface characteristics and demonstrates the ability of the source rock and confining layers to contain the frac job.
- Are operators required to conduct a survey of permitted and unpermitted wells within the anticipated zone of directional drilling and fracturing?
- What mechanisms are available to state agencies to ensure permit compliance and proper calibration of best available control technologies for drilling and fracturing over time?
- Is there a way to require companies to buy insurance on each individual well?
- Establish a state fund to facilitate public agencies' ability to assess and enforce permit compliance.
- How can local/county governments gain access to best available data to inform local land use and resource management decisions?
- What role can local/county governments play in water and air monitoring efforts?
- Does the State of Wyoming have a plan or process to assess cumulative impacts of hydraulic fracturing?
- Create a state-level process for environmental assessment and monitoring similar to the federal NEPA/EIS process used on BLM land.
- Better analysis and interpretation of existing state data to identify potential patterns.
- How will the state implement lessons learned from the Pinedale Anticline, Jonah Field and Pavillion to new plays such as the Niobrara?

Water, Air and Soil Science

- Assessment of cumulative water supply impacts of hydraulic fracturing in the context of other water supply demands such as agricultural and municipal use.
- Develop better metrics for tracking flowback versus produced water.
- How much flowback water is disposed of in evaporation ponds? What is the fate of chemicals in flowback water? Is cradle-to-grave tracking of flowback water possible?
- Improved quantitative research on air emissions from flowback and produced water from hydraulic fracturing.
- Improved monitoring and assessment of the risk and potential impacts of sub-surface gas migration into groundwater.

- What are the risks associated with surface spills of frac fluid before it is injected? What measures are taken to prevent them?
- Implement synthetic liners and berms to contain spills at well pads.
- What is the risk to birds from flowback evaporation ponds?
- Baseline and long-term studies on thermogenic methane release from soils above fractured areas.
- Studies to determine an effective testing and calibration regime for air pollution sources.
- Meteorological and chemical modeling to simulate wintertime ozone levels so that more effective emissions controls for VOCs and/or NOX can be identified.
- To what extent are portable methane detectors available?
- Additional study of the potential for hydraulic fracturing to induce earthquakes in seismically active areas.
- What are the lifecycle contributions of hydraulic fracturing to greenhouse gas emissions?

Public Health

- What are the frac fluid chemicals that pose the greatest exposure risk to human health? What is the magnitude of exposure or not?
- What work practices at well sites pose the greatest risk for exposure?
- What are the public health risks associated with the potential intersection of fracturing, abandoned wells, and groundwater?
- What are the potential impacts of hydraulic fracturing and related activities on livestock?
- Baseline and long-term public health assessments to identify potential acute and chronic human health risks associated with oil and gas development and hydraulic fracturing.
- Epidemiological and occupational health studies, including impacts of ozone mixing with other chemicals in the air, as well as effect of altitude on the body's ability to cope with chemical stressors.
- Incorporate human health impacts of fracturing into worker safety trainings once better information is available.

Public Information

- Foster a culture of support for concerned residents through increased transparency and public outreach around oil and gas undertakings through collaboration between local governments, industry, and non-governmental organizations.
- Produce and disseminate case studies that illustrate all steps of the hydraulic fracturing process, from pre-planning and site characterization, to securing water resources, performing the frac and completing the well, to managing flowback and produced water.
- Establish a website where the public can get objective answers, possibly through a collaborative body, to questions and concerns.

Conclusion

Participants were thanked for their attendance and the meeting was adjourned. Materials and presentations from the forum are available at www.uwyo.edu/SER/conferences/hydraulic-fracturing.